INSTITUTO SUPERIOR DE AGRONOMIA
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Study of the relationship between rainfall, runoff and land use in five watersheds

Drought and impacts on the landscape system

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Dissertation for obtaining Master degree in

Landscape Architecture

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ABSTRACT

The amount of water generated from a watershed depends on the climate, soils, geology, vegetation and land use. Water inputs of precipitation as rain are divided by watershed in the evapotranspiration, runoff and groundwater recharge. This study examined the factors that can affect the runoff of Portuguese watersheds, focusing on factors related to land and watershed management.

For this analysis, a methodology developed by Thornthwaite-Mather was used to compute streamflow with the input of precipitation and temperature obtained by Portuguese Meteorology Services. These data were compared with the observed values in order to be able to calculate soil properties, in this case, the values of coefficient of reservoir and available water content. These values are possibly related to changes in the composition of the soil and were compared with the values of land use for periods studied based on CORINE methodology (1970 to 2006).

The existence of periods of drought, calculated with SPI-12months and their impacts were also compared with changes in soil and land use.

These processes are the main steps for understanding the changes that affect all these systems. These changes are important for the planning future landscape management.

Key-Words: watershed, drought, land use, Thornthwaite-Mather, landscape ecology.

RESUMO

A quantidade de água gerada a partir de uma bacia hidrográfica depende do clima, solos, geologia, cobertura vegetal, e uso do solo. Os *inputs* de água provenientes da precipitação, como a chuva, são divididos pela bacia hidrográfica em evapotranspiração, escoamento superficial e recarga de aquíferos. Este estudo analisou os fatores que afetam o escoamento nas bacias hidrográficas, focando fatores relacionados com o solo e à gestão de regiões hidrográficas.

Na análise, é utilizada uma metodologia desenvolvida por Thornthwaite-Mather em que foram comparados dados de escoamento estimando a partir da precipitação e temperatura atribuído pelos Serviços Portugueses de Meteorologia. Os dados são comparados com os valores reais do Serviço Português de Meteorologia de escoamento de modo a calcular as propriedades do solo, como os valores de coeficiente de reservatório e do teor de água disponível. Estes valores estão relacionados com mudanças na composição do solo e são comparados com os valores de ocupação de solo para vários períodos de tempo com base na metodologia CORINE (de 1970 a 2006).

A existência de períodos de seca, calculados com SPI-12 (Índice de Precipitação Padrão) e os impactos são também comparados com as alterações do solo e sua ocupação.

Palavras-Chave: Bacia hidrográfica, Seca, Ocupação de solo, Thornthwaite-Mather, Ecologia de paisagem.

RESUMO ALARGADO

A paisagem encontra-se em constante mudança e a sua dinâmica pode ser entendida como um processo de transformação das relações estabelecidas entre os elementos que a compõem. Para a compreender, é assim necessário, identíficar os fatores que vêm a determinar a sua transformação. Assim sendo, a maneira como esta é naturalmente ou artificialmente transformada irá afetar toda a sua dinâmica num determinado período de tempo.

A quantidade de água gerada a partir de uma bacia hidrográfica depende do clima, dos solos, da geologia, da cobertura vegetal, e do uso do solo. Os *inputs* de água proveniente da precipitação na forma de chuva ou neve são divididos pela bacia hidrográfica em evapotranspiração, escoamento superficial e recarga de aquíferos.

Neste estudo concreto, são analisados os fatores que podem afetar o escoamento nas bacias hidrograficas portuguesas com foco em fatores relacionados com a climatologia, os solos, e a gestão dada ao uso do solo existente nestas bacias. Torna-se então imprescindível compreender estas mudanças (que podem ser as mais variadas, desde do reflorestamento, ao desmatamento, à criação de solos agrícolas, ao uso urbano e ao impacto do escoamento superficial).

Para poder compreender as mudanças de uso no solo foi utilizada a metodologia do balanço de água no solo, desenvolvido por Thornthwaite-Mather, nos quais foram utilizados os dados de precipitação e temperatura retirados dos Serviços Portugueses de Meteorolgia (Instituto Português do Mar e da Água). Após a entrada destes dados no modelo, são calculados os valores de escoamento através deste modelo de Thornthwaite-Mather, e comparados com os valores reais provenientes, também, dos Serviços Portugueses de Meteorologia. Após esta comparação, serão otimizados os valores referentes às propriedades do solo (teor de água disponível e o coeficiente de escoamento). Estes valores são comparados com os valores de ocupação do solo para os vários periodos de tempo com base na metodologia CORINE (neste caso para os anos 1970, 1990, 2000 e 2006).

Depois são calculados os períodos de seca, através do cálculo dos valores de SPI (Índice de Precipitação Padrão) e discutidos os seus possíveis impactos na ocupação de solo.

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LIST OF ABBREVIATIONS

AET – Actual evapotranspiration

APA – Portuguese Environment Agency

APWC – Accumulated potential water loss

AWC – Available water capacity

CORINE – Coordination of information on the environment

DL – Drought month duration

DM – Drought magnitude

DMM – Drought average magnitude

ET – Evapotranspiration

ET_0 – Reference evapotranspiration

ETP – Potential evapotranspiration

f – Coefficient of reservoir

FAO – Food and Agriculture Organization of United Nations

INAG – Portuguese Water Institute

K_c – Cultural Coefficient

RH – Hydrographic region

SNIRH – National Information System in Hydric Resources

SPI – Standard precipitation index

SWB – Soil water balance

PMS – Portuguese Meteorology Service

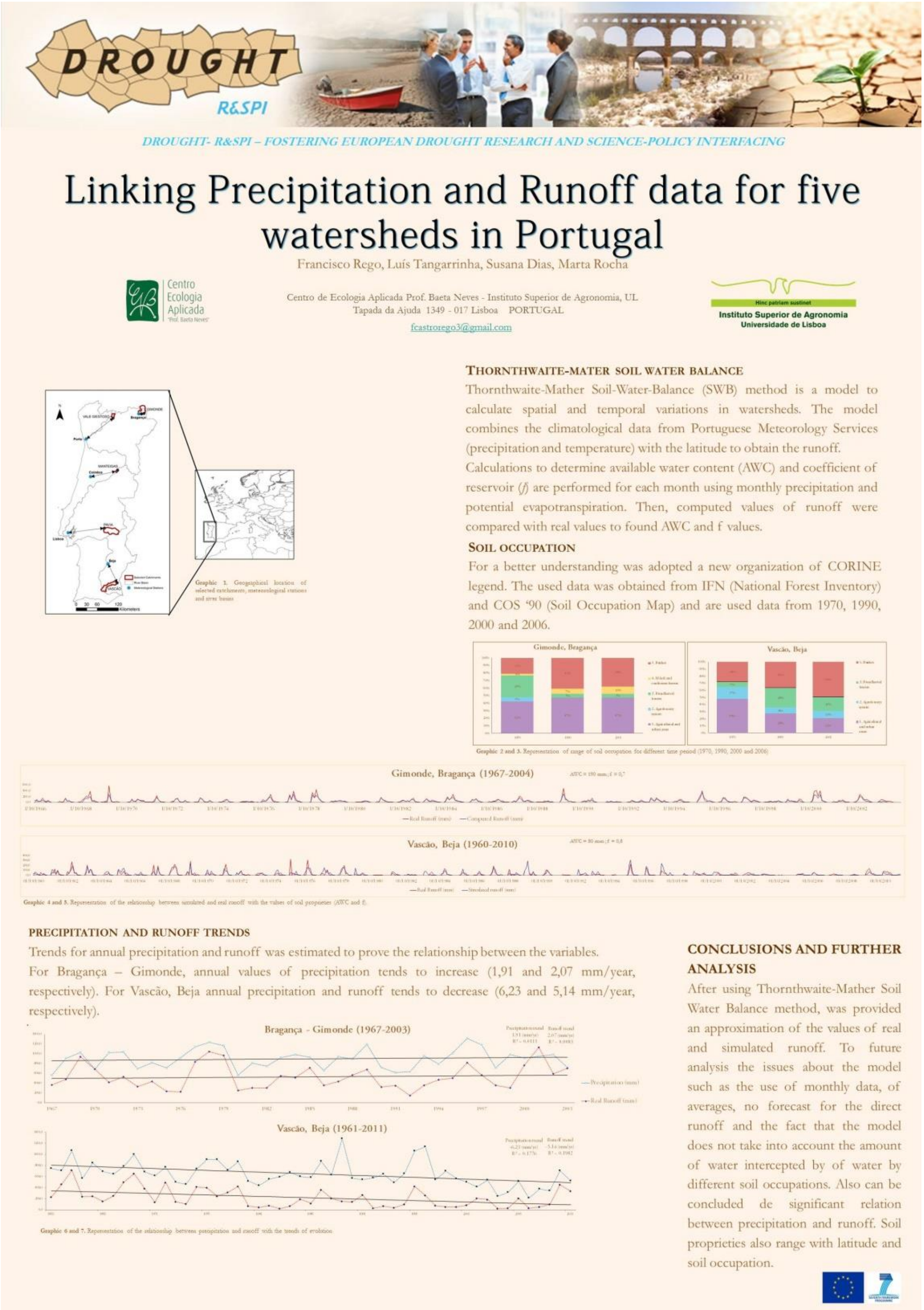
0. Dissertation framework

Starting with justification why this dissertation is written in English. This dissertation was incorporated in the DROUGHT R&SPI project.
Drought is natural hazard that has hit Europe hard over the last decades. Likely it will become more frequent and severe and the scale will increase due to the increased likelihood of warmer Northern winters and hotter Mediterranean summers. There is an urgent need to improve drought preparedness through increased knowledge on the past and future hazard, impacts, and possible management and policy options, measures, and through drought management plans and an improved science-policy interfacing. This will reduce vulnerability to future drought and the risks they pose for Europe. DROUGHT-R&SPI will address this pressing need. (Lanen, 2013).

The main project objectives are:

- Drought as a natural hazard, including climate drivers, drought processes and occurrences;
- Environmental and socio-economics impacts;
- Vulnerabilities, risks and responses.

Then was done a poster of this dissertation for a presentation in Lisbon on October 2013;



Lisbon, October de 2013

Drought R&SPI Project

http://www.eu-drought.org/

1. INTRODUCTION

The hydrologic system is complex and it extends through all the parts of the earth's system. The landscape system is a part of the earth's system and it's dynamic components need to be the key for its own planning. One of the main targets of this study is to understand in which way the hydrographic system is related with the landscape system. In watersheds, there are components of the landscape that are modeled by the hydrological system as vegetation and soil.

The following thematic study: Landscape planning and vulnerability assessment in the Mediterranean brings attention to the methodologies used in spatial planning, in particular landscape planning approaches that allow the integration of various land uses and protection of landscape values through planning instruments.

To efficiently fulfill the new tasks, the landscape planning functions should be optimally coordinated with other relevant planning and assessment instruments. Due to pending and anticipated changes, the continuation and updating of landscape planning will be particularly important. Flexible, modular and conclusive digital processing, which is aimed at problem related planning statements oriented to the need for action, is indispensable for this.

The main purpose of this project is to find linkages between landscape system, land use, and precipitation-runoff relationships, that let us know the consequences of landscape changes in hydric behavior of watersheds.

"A few studies have so far been published on the effect of climate change on the impacts of drought in water resources terms at the local catchment scale, and there are no reported studies on the relation between precipitation and stream flow trends specifically for Portugal, which is considered one of the areas of the Iberian Peninsula most affected by significant climatic changes". (Rego, Acácio, Van Lanen, & Stahl, 2013).

Starting from this principle, there was some concern about starting to study more this issue. In order to understand this problem, few water balance models were studied. In this specific case the model used was a very simple mode, the Thornthwaite-Mather water balance model because it is possible to calculate the runoff using precipitation, temperature and with it latitude. Since one of the main targets of this study is planning the landscape and a comparison between the calculated values obtained through the Thorthwaite-Mather soil water balance model with the actual flow data from the Portuguese Meteorological Service (Institute of Meteorology) was done. After comparing all these values, it is necessary to optimize the variables soil characteristics as well as the available water capacity and coefficient of reservoir. These values will be optimized during the study, making it possible to find a range on the soil's response to water. Being this response an important step to understand some ranges in land use.

Using land use data from Forestry National Inventory of some strategic periods as 1970, 1990, 2000 and 2006 and using the CORINE legend(Coordination of information on the environment) it was created a new scale for better understanding of the relationship of the most abundant classes of used data. To study the dynamic of landscape system it is necessary to compare the effect of water on soil's response, ranging the land use.

It also important to study the drought impacts and modifications on the landscape system. Using the Standard Precipitation Index to calculate the magnitude of the drought, to split the classes where the water shortage is more aggressive. After that it is also important to compare the main droughts calculated with land use range.

By the way, landscape ecology is a science that tries to explain the operation of landscape system and the landscape architecture as the main target of make an intervention in landscape system for improve his operations.

1.1. Hydrologic Cycle

The hydrological cycle (figure 1) is usually called a recurring consequence of different forms of movement of water and changes of its physical state in the nature on a given area of the earth (a river or lake basin, a continent or the entire earth). The movement of water in the hydrological cycle extends through the four parts of the Earth’s total system – atmosphere, hydrosphere, lithosphere, and biosphere – and strongly depends on the local peculiarities of these systems. The terrestrial hydrological cycle is of a special interest when referring to mechanism of formation of water resources on a given area of the land. Taking into account its global climate and other geophysical processes, the global hydrological cycle is often considerated. It is obvious that the role of different processes in the hydrological cycle in their description have to depend on the closer spatial-temporal scales. (Kuchment, 2001).

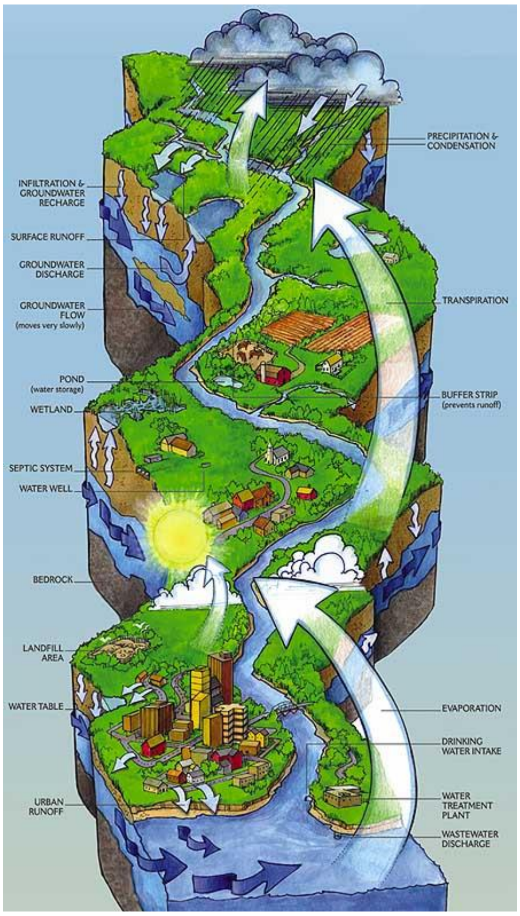


Figure 1 - Hydrologic System scheme (Jackson, 2008)

The total amount of water on Earth is divided in three phases that have kept constant since the appearance of man: solid, liquid and gaseous. It is also divided into three main reservoirs: oceans, continents and the atmosphere, among which there is a continuous circulation in a process called Hydrological Cycle. (Pinto, Holtz, & Martins, 1973). In liquid and solid forms, the water covers more than two thirds of the land’s surface, but in its gaseous form it is considerate a variable component of the atmosphere (which can take up to 4% of the whole volume). Under such conditions, water vapor is in its major quantity in the tropics and in the lower layers of the atmosphere. (Camargo, 2005). Water is composed by molecules that attract one another by the force of cohesion. These molecules in the liquid state are in constant motion, moving vertically towards the atmosphere and horizontally towards the surface. This movement is proportional to the energy or temperature of water. If the temperature increases, the rougher surface molecules tend to escape of the liquid water mass and keep the atmosphere free in its gaseous state. If the temperature of liquid water decreases, the movement of the molecules decreases as well. If the temperature reaches zero centigrade, the water molecules are fixed and solidify, forming ice. So, the Hydrological Cycle is composed by a succession of various processes in nature, where the water starts going in a typical way on an early stage, to return to its original position. This global phenomenon of closed circulation of water between the land surface and the atmosphere is fundamentally driven by radiant energy and associated with terrestrial gravity and rotation. It is estimated that about 10% of the total vapor is used to recycle.

The land surface that covers the continents and oceans , such as the porous layer overlying continents (soils, rocks) and the reservoir formed by lakes, the rivers and the oceans take part in the whole hydrological cycle. Part of it is formed by the circulation of water on the surface itself and by the movement of water in and on the surface of the soil, rocks, lakes and other liquid surfaces and living things (such as animals and plants).

1.2. Drainage basin

Playfair (1802) described drainage basins as trees, where each stream would delicately be adjusted such that at each joining of streams, the slopes would delicately be balanced. The systematic change of the slope within landscapes suggested to Playfair that the equilibrium between erosion and sediment transport over the entire basin, and a stable geometry would result from this balance. Another author, Gilbert (1977), noted that erosional landforms have convergent stream networks and divergent ridge networks, and proposed that the typical concave-up profile of streams is due to the increased volume of water moving through downstream sections into the drainage network. He postulated that gaps between adjacent streams must migrate toward the stream with a shallower gradient; stable channel networks are achieved once gradients in adjacent streams are similar. The instability of drainage lines could be explained in terms of differential resistance to erosion, differential uplift, time and, possibly, the interaction between stream transport capacity and availability of sediment for transport. For Gilbert, the network of streams and hill slopes is a strongly interactive system, carefully adjusted to the dynamic equilibrium into a stable form (Gilbert, 1877). Strahler (1950) characterized erosional landscapes as open mass-transport systems that adjust their morphology to attain a time-independent form. He measured valley-side slope angles from several completely dissected natural drainages, and showed that a given area maintains a characteristic slope with a narrow range of values. The presence of a characteristic slope lends support to the hypothesis of a stable landform (Strahler, 1950). Hack hypothesized that every stream hill slope pair is adjusted one to the other, and, given constant forcing conditions, all elements of the landscape erode at the same rate, similar to Gilbert's dynamic equilibrium. Differences in form could, under those conditions, be related only to differences in resistance to flow, such as variable lithology and vegetation. Changes in the form could also result from different forcing conditions, even thou responses to perturbations are fast enough to restore a dynamic steady state adjusted to the new boundary conditions. He explicitly viewed landscapes as spatial structures with time-independent forms. (Hack, 1960).

Figure 2 shows a scheme of hydrological system.

For Tonello (2005), the morphometric characteristics can be divided in: geometrics, land relief and drainage, shown on table 1.

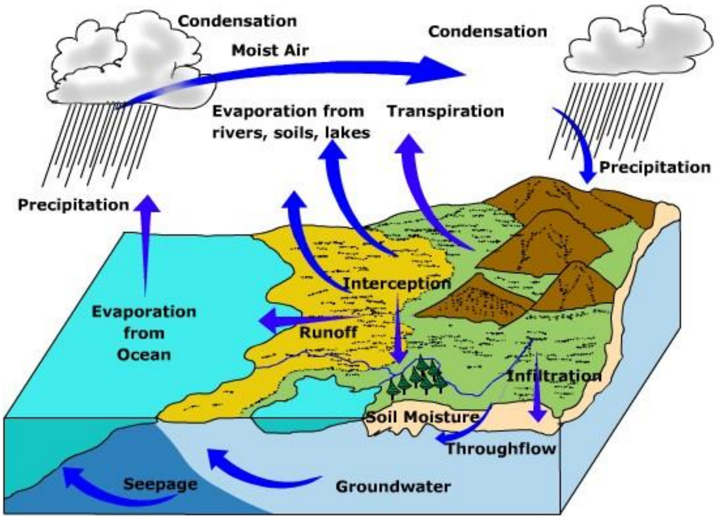


Figure 2 - Scheme of Hydrological System

Morphometric characteristics	**Type of analyses**
Geometric characteristics	✓ Total shape area ✓ Total perimeter ✓ Coefficient of Compactness **(Kc)** ✓ Form factor **(F)** ✓ Circularity index **(IC)** ✓ Drainage pattern
Land relief characteristics	✓ Orientation ✓ Minimum slope ✓ Medium slope ✓ Maximum slope ✓ Minimum altitude ✓ Medium altitude ✓ Maximum altitude ✓ Medium slope of main watercourse
Drainage characteristics	✓ Length of main watercourse ✓ Total length of watercourse ✓ Drainage density ✓ Order of watercourses

Table 1 - Morphometric characteristics and type of analyses for drainage basin

1.2.1. Geometric characteristics

a) Area: Total area drained by the river system included among its topographic dividers, designed in the horizontal plane, being a basic element for the calculation of various morphometric indices.

b) Perimeter: Length along the imaginary line of splitter waters.

C) Form Factor **(F)**: It compares the shape of the basin with a rectangle, corresponding to medium width ratio between the medium width and the axial length of the basin (from the river mouth to the furthest point of the river spike) and may be influenced by some features, mainly by geologic factors. It can also change due to some of hydrological processes on the hydrologic behaviour of basin. The form factor can be described by the following equation:

$$F = \frac{A}{L^2}$$

Where, **F** = Form factor; **A** = Drainage area; **L** = Axis length of the basin

d) Coefficient of compactness **(Kc)**: Lists the shape of the basin with a circle. Is the ratio between the perimeter of the basin and the circumference of a circle of equal area as the basin. This coefficient is a dimensionless number which varies with the shape of the basin, regardless its size. The more irregular the basin is, the higher the coefficient of compactness. A minimum coefficient equal to one unit corresponds to a circular basin and for an elongated basin, its value is significantly greater than one, and may be calculated by the following equation:

$$Kc = 0{,}28 \times \frac{P}{\sqrt{A}}$$

Where, **Kc** = Coefficient of compactness; **P** = Perimeter; **A** = Drainage area

e) Circularity index **(IC)**: Simultaneously with the coefficient of compactness, the circularity index tends to the unity as the basin approaches the circular shape, and decreases as the shape becomes elongated, according to the equation:

$$IC = \frac{12{,}57 \times A}{P^2}$$

Where, **IC** = Circularity index; **A** = Drainage area; **P** = Perimeter

f) Drainage pattern: Is the relationship between the number of rivers or watercourses and the catchment area expressed as follows:

$$Dh = \frac{N}{A}$$

Where, **Dh** = Drainage pattern; **N** = Number of rivers or watercourses; **A** = Drainage area

The target of this index is to compare the frequency or the amount of existing watercourses area in a standard size, such as square kilometer.

1.2.2. Relief characteristics

a) Slope: The slope is related to the speed that gives superficial runoff therefore affecting the time it takes for the water from the rain to concentrate on riverbeds. This constitutes the drainage network basins, with the peaks of flood, infiltration and susceptibility to soil erosion depending on the speed with which the flow occurs on the land basin.

b) Altitude: The altitude variation is associated to precipitation, evaporation and transpiration and thus on average runoff. Great variations of a basin altitude cause significant differences in medium temperature, and it causes variations in the evaporation. More significant, however, are the possible variations of annual precipitation with elevation.

c) Amplitude altimetry: is the variation between the maximum altitude and minimum altitude.

1.3. Portuguese water legislation

The Portuguese water law (Portuguese Law n.º 58/2005, of 29th December), which transposes into national law the EU Water-Framework Directive (Directive no. 2000/60/EC of 23th October), establishes the framework for the management of surface water, including inland waters, transitional, coastal and underground waters.

The main unit for management of watersheds is the river basin district (was the basin), which corresponds to the area of land and sea, made up of one or more contiguous watersheds and underground water’s and coastal and their associated.

The Portuguese water law establishes 8 river hydrographic regions (RH) in Portugal, whose boundary is defined by normative geo referenced own, present on figure 3.

The river basin is also the main planning unit of water, being this achievement possible due to the use of three instruments, in particular through the Management Plans Hydrographical Region (PGRH).

1.3.1. Management Plan of Hydrographical Region

The Management Plan of Hydrographical Region, whose content is defined in art. 29 of the Portuguese water law, pretends to establish the basis of support for management, protection and appreciation of the environmental, social and economic waters. These plans cover watershed's integrated river basin districts, estuaries, coastal areas and associated aquifers.

According to the decree-law that defines the content of Management Plan of Hydrographical Region, these will have to be mandatorily incorporated in the Master Plans in order to function as regulatory instruments of relations between the administration and citizens as well as agents of socio-economic development, in relation to the Water.

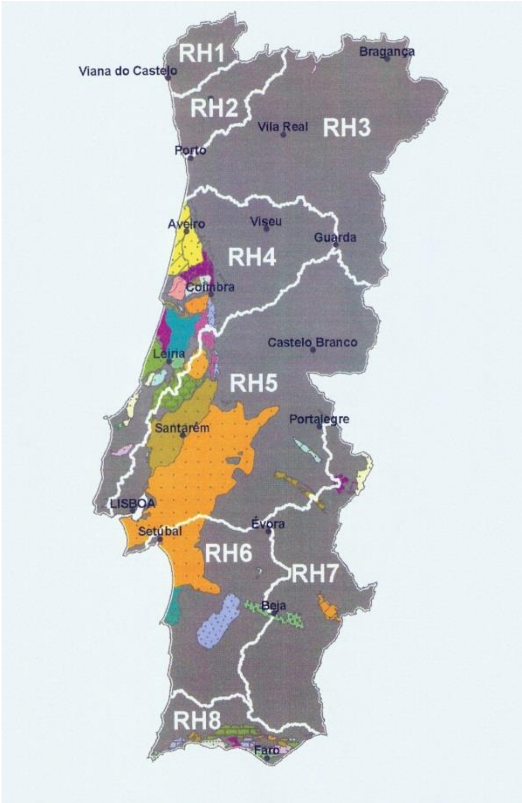


Figure 3 - Hydrographic regions of Portugal (Azinhal Algarve, 2008)

The Management Plan of Hydrographical Region will include a general description of the river basin, a characterization of natural pressures and impacts related to human activity, and a significant program of measures to ensure the continuation of the environmental objectives set out in the Portuguese Water Law. (Rosas).

1.4. General definitions

1.4.1. Precipitation

Precipitation is the water that reaches the Earth's surface from the water vapor in the atmosphere, in the form of rain, sleet, snow and dew. The quantitative characteristics of rainfall measurements are: (Pedrazzi)

- Height rainfall - rain measures made in the rain gauges and expressed in millimeters. Is the water depth to be formed on the soil as a result of some rain, if there were no runoff, infiltration or evaporation of the precipitated water;
- Duration - the period of time starting from the beginning to the end of precipitation, usually expressed in hours or minutes;
- Precipitation intensity - is the ratio between the height and duration of rain precipitation expressed as mm / h or mm / min.

Medium precipitation over a basin

To calculate the average precipitation of any surface, it is necessary to use the comments of the posts within that area and its neighborhoods.

There are three methods to calculate the average rainfall:

- Method of Arithmetic mean;
- Method of Thiessen; and
- Method of Isoietas.

Method of Arithmetic mean:

Arithmetic mean consists on the sum of precipitation observed in positions that are inside of the basin being the result divided by their number.

This method is only recommended for basins smaller than 5000 km, with rain gauges evenly distributed on a flat area or gentle slope.

Method of Thiessen

Thiessen polygons are areas of "domain" of a rainfall station. It is considered that within these areas is the same precipitation altitude of the respective post. The polygons are drawn as follows:

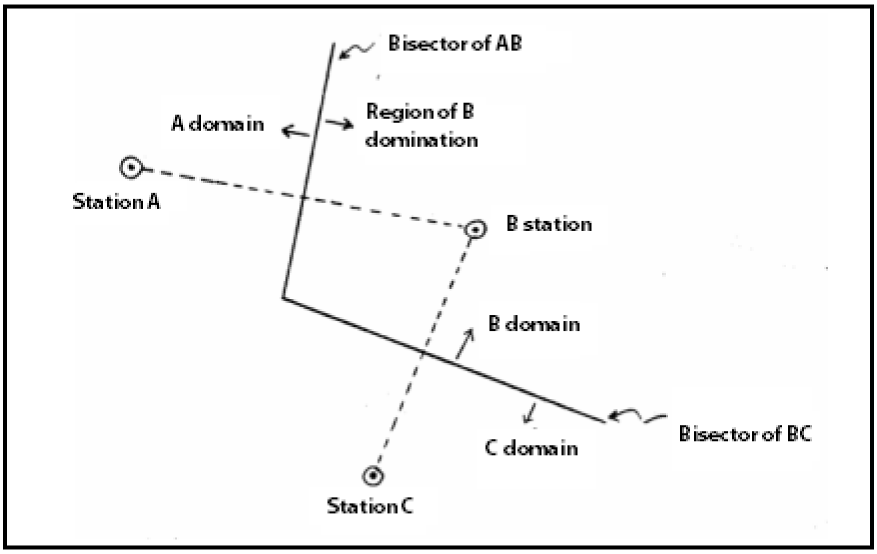


Figure 4 - Thiessen method (scheme)

1st. Two adjacent stations are connected for a line (figure 4);

2nd. Traces the bisector of this line. This bisector divides from one side to another, the regions of "domain".

3rd This procedure is initially performed by any position (for exemple, station B), connecting it to the adjacent. It is defined in this way, the polygon of that position (figure 5).

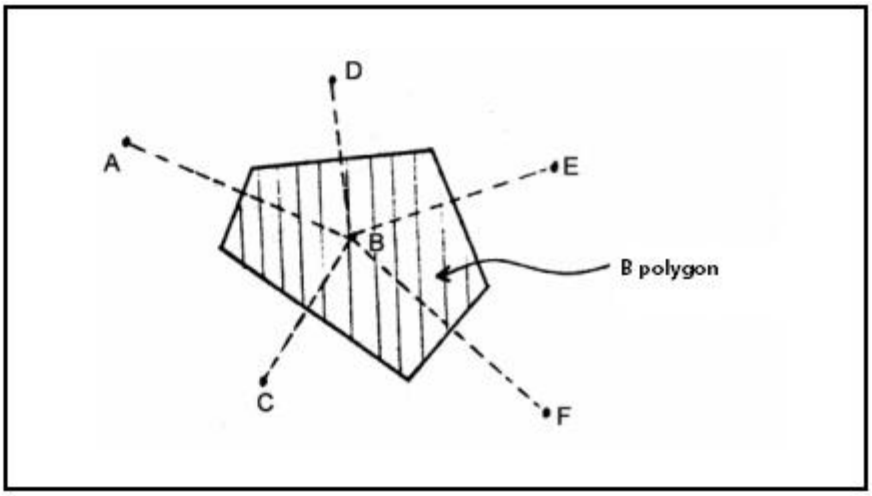


Figure 5 - Determination of B polygon

4th. Repeat the same procedure for all stations.

5th. Disregard the areas of the polygons that are outside the basin.

6th. The medium rainfall in the basin is calculated by the following equation:

$$\bar{P} = \frac{\sum_{i=1}^{n} AiPi}{A}$$

$\bar{\boldsymbol{P}}$, is the medium precipitation on the basin (mm)

$\boldsymbol{Pi}$, is the precipitation on the station (mm)

$\boldsymbol{Ai}$, it's the shape area of the polygon inside the basin (km^2)

A, it's the total area of the basin (km^2).

Method of Isoietas

Isoietas method are indicative lines of the same height rainfall. Spacing lines can be set based on the type of study being developed and may be 5 by 5 mm, 10 by 10 mm, etc.

Isoietas need to be drawn up in the same way as the counter lines in topography in the presence of rainfall in some raised stations.

The Isoietas method is established by following steps:

1st. define the desired spacing between the Isoietas;

2nd. connects with a semi-line, two adjacent stations, putting their respective rainfall heights;

3rd. interpolates linearly determining the points where they will pass the level curves, within the range of two heights rainfall (figure 6).

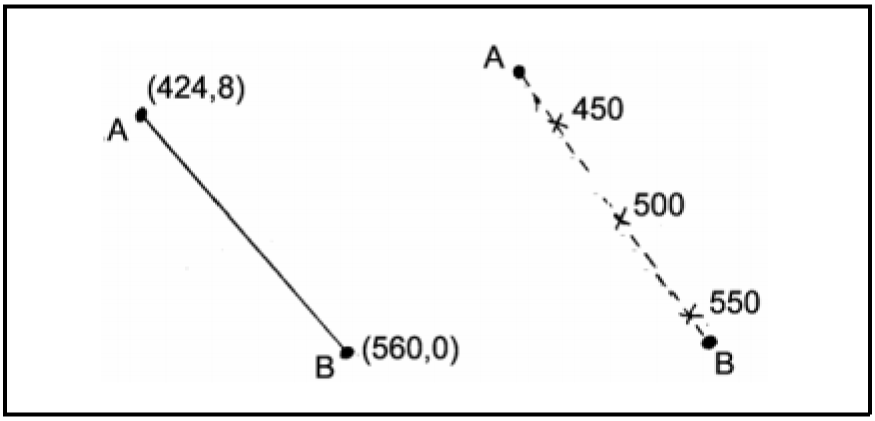


Figure 6 - Determination of point where the level curves will pass

4th. proceed that way with all the adjacent rain gauges;

5th. link up the points of same height rainfall, determining each isoietas;

6th. the medium rainfall is calculated by the following equation:

$$\bar{P} = \frac{\sum_{i=1}^{n} \overline{P\iota \, . \, A1}}{A}$$

$\bar{P}$, medium precipitation on basin

$\bar{P}i$, arithmetic means of two followed isoietas “I” and i+1”

Ai , is the shape area of the basin between two respected isoietas (km_2)

A , is the total area of basin (km_2)

1.4.2. Evapotranspiration (ET)

Evaporation and transpiration occur simultaneously and there is no easy way of distinguishing between the two processes. Apart from the water availability in the topsoil, the evaporation from a cropped soil is mainly determined by the fraction of the solar radiation reaching the soil’s surface. This fraction decreases over the growing period as the crop develops and the crop’s canopy shades cover more and more the ground’s area. When the crop is small, water is predominately lost by soil evaporation, but once the crop is well developed and completely covers the soil, transpiration becomes the main process. In Figure 7 the partitioning of evapotranspiration into evaporation and transpiration is plotted in correspondence to leaf area per unit surface of soil below it. At sowing nearly 100% of **ET** comes from evaporation, while at full crop cover more than 90% of **ET** comes from transpiration. (Allen, Pereira, Raes, & Smith, 1998)

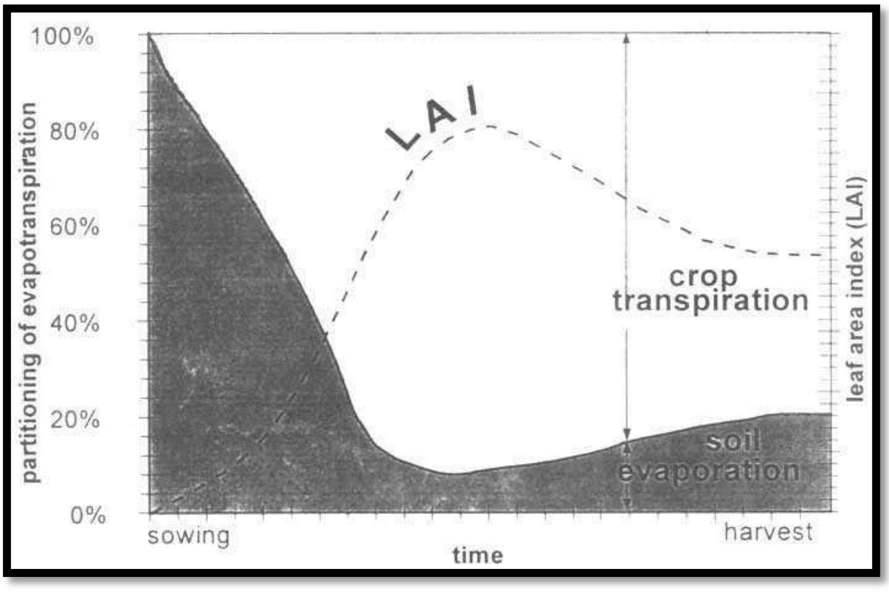


Figure 7 - The partitioning of evapotranspiration into evaporation and transpiration over the growing period for an annual field crop

1.4.3. Potential evapotranspiration (ETP)

Potential evapotranspiration (**ETP**), according to Penman (1956), is the total amount of water for a large area completely covered with vegetation stature and well supplied with water. Some meteorological variables are determinants of evaporation and evapotranspiration. The temperatures of the air and water are greatly related to solar radiation and therefore also correlate positively with evaporation. The effect of wind on evaporation is exercised by the removal and replacement of the air just above the evaporating surface. In other equal conditions the evaporation is proportional to the difference between the saturated vapor pressure of water at the temperature and pressure of the vapor in the air.

The concept of potential evapotranspiration, the most significant advance in understanding the aspects of climate humidity, was introduced in 1944 by Thornthwaite. The potential evapotranspiration (**ETP**) has been considered as the rain, representing the rain needed to fit water requirements of vegetation. Evapotranspiration reliable data are required for the planning, construction and operation of reservoirs and irrigation systems and drainage, thus reducing the cost required for irrigation of agricultural cultivars. The Thornthwaite-Mather method is widely used in all regions, since it is based only on the temperature, which is usually collected in a given weather stations. (Mather, 1958)

1.5. Thornthwaite-Mather method

Thornthwaite-Mather Soil-Water-Balance (**SWB**) method is a model to calculate spatial and temporal variations in watersheds. The model combines the climatological data (precipitation and temperature) with the latitude to obtain the runoff.

Thornthwaite (1948) correlated mean monthly temperature with **ET**, as determined from water balance for valleys in the eastern United States of America where sufficient soil water was available to maintain active transpiration. The Thornthwaite formula for monthly $\mathbf{ET_0}$ (mm) is:

$$\mathbf{ET_0} = 16\,\mathbf{d}\,(10\mathbf{T}/\mathbf{I})^{\mathbf{a}}$$

Where **T** is the mean temperature for the month (in °C), **I** is the annual thermal index. The sum of monthly indices **i** [$i = (T/5)^{1.514}$], **d** is a correction factor which depends on latitude and month, and **a** is $0.49 + 0.0179\,I - 0.0000771\,I^2 + 0.000000675\,I^3$. (Chen , Gao, Guo, & Ren, 2005)

The figure 8 explains how the different conceptual portions of a watershed are combined in the Thornthwaite-Mather model.

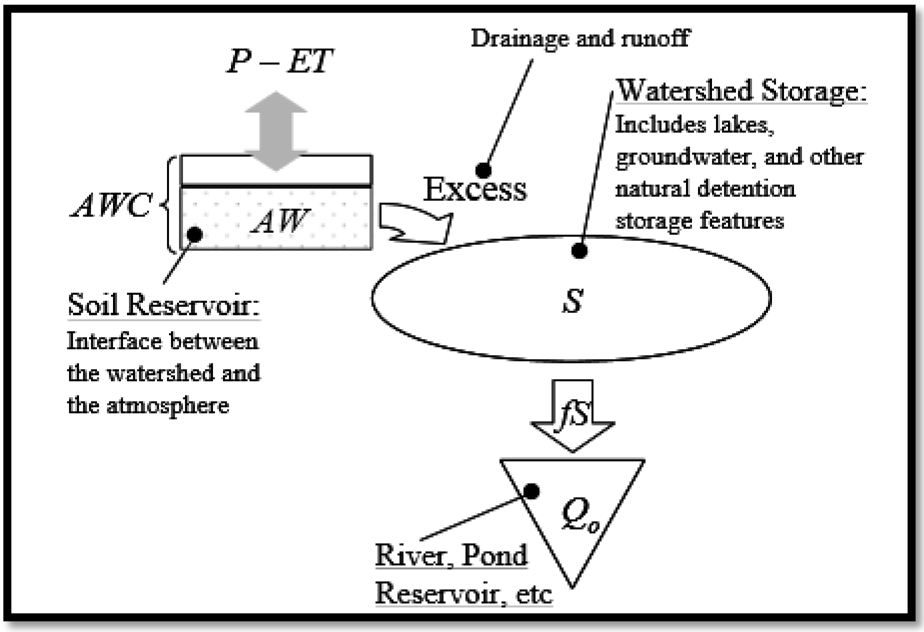


Figure 8 - The soil reservoir and how it connects to stream discharge at the watershed outlet, Q0 (Chen , Gao, Guo, & Ren, 2005)

Determining the soil water budget is the most difficult part of the Thornthwaite-Mather method.

Notation:

AWC = Available Water Capacity

AW = Available Soil Water

ΔP = Net Precipitation; P-PET

P = Precipitation

PET = Potential Evapotranspiration

Calculations to determine available water capacity (**AWC**) are performed for each month using monthly precipitation (**P**) and potential evapotranspiration (**PET**). Excess water (**ΔP**) in excess of the available water content (**AWC**) leaves the soil and is stored in the watershed and eventually released to the river. Table 2 explains the situation of dry/wet in watershed.

Situation in the Watershed	AW	Excess
• <u>Soil is drying</u> $\Delta P < 0$	$= AW_{t-1} \exp\left(\frac{\Delta P}{AWC}\right)$	$= 0$
• <u>Soil is wetting</u> $\Delta P > 0$ but $AW_{t-1} + \Delta P \leq AWC$	$= AW_{t-1} + \Delta P$	$= 0$
• <u>Soil is wetting above capacity</u> $\Delta P > 0$ but $AW_{t-1} + \Delta P > AWC$	$= AWC$	$= AW_{t-1} + \Delta P - AWC$

Table 2 - Situation (of dry/wet) in watershed (Chen , Gao, Guo, & Ren, 2005)

Watershed Storage and River Discharge:

All *Excess* water, water above the available water capacity, goes into watershed storage (***S***), which in-turn, feeds river discharge (***Q₀***) from the watershed.

$\mathbf{S_t} = S_{t-1} + \textit{Excess}$

Is commonly assumed that discharge is a constant fraction of watershed storage, especially for groundwater discharge into rivers.

$\mathbf{Q_0} = f\, S_t$

Where ***f*** is the coefficient of reservoir and usually ***f*** < 1. Stream flow data are available, so ***f*** can be optimized using correlations values. (Walter, 2013)

Problems with this method:

- Use of averages
- Use of monthly interval
- No provision for direct runoff
- No provision for interception

1.5.1. Actual Evapotranspiration (AET)

When **P – PET** is positive, the actual evapotranspiration equals the potential evapotranspiration. When **P – PET** is negative, the actual evapotranspiration is equal to the amount of water that can be extracted from soil (**ΔSW**).

1.5.2. Surplus

If the soil moisture reaches the maximum soil-moisture capacity, the excess precipitation is added to the daily soil-moisture surplus value.

1.5.3. Accumulated Potential Water Loss (APWL)

The accumulated potential water loss is calculated as a running sum of the daily **P - PE** value during periods when **P - PE** is negative. Usually soils yield water easily during the first days in which **P - PE** is negative. On subsequent days, as the **APWL** grows, soil moisture is less readily given up.

1.5.4. Deficit

The daily soil-moisture deficit is the amount by which the actual evapotranspiration differs from the potential evapotranspiration. The soil-moisture surplus and deficit terms have no direct bearing on the calculation of recharge.

1.5.5. P minus PE (P-PE)

The first step in calculating a new soil moisture value for any given grid cell is to subtract potential evapotranspiration from the daily precipitation (**P - PE**). Negative value of **P - PE** represents the potential deficiency of water, whereas positive **P - PE** value represents the potential surplus of water.

1.5.6. Soil water and change in soil water (SW and ΔSW)

The soil water tern represents the total of water held in soil storage for a given cell grid. Soil water has an upper bound that correspond the soil's maximum water-holding capacity (roughly equivalent to the field capacity); soil water has a lower bound that corresponds to the soils wilting capacity.

If **P - PE** is positive, the new soil water value is found by adding this **P - PE** term directly to the proceeding soil water value. If the new soil water value is stilling below the maximum available water capacity (**AWC**), the Thornthwaite-Mather soil water tables are consulted to recalculate a new value. Then, reduced accumulated potential water-loss value generates a new value.

If new soil water value exceeds the maximum available water capacity value (**AWC**), the excess is converted to recharge, and the accumulated potential water-loss term is reset to zero.

But, if **P - PE** is negative, the new soil water value is found by looking the soil water value in the Thornthwaite-Mather tables.

1.5.7. Runoff

The runoff is the amount of water that falls on the soil and isn't infiltrated, evaporated or evapotranspirated. The calculation is obtained through the product of the coefficient of reservoir and surplus.

1.5.8. Detention

Detention is the fraction of the storage that hasn't been transformed in runoff. Is the fraction of water that keeps on the soil.

1.5.9. Actual flow

The actual flow is the Portuguese Meteorological Service (Institute of Meteorology) data for runoff. It will be compared with runoff computed with the soil's water balance of Thornthwaite-Mather.

1.5.10. Available water capacity (AWC)

Reed, Maidment, & Patoux (1997) defined the field capacity as the content of a soil that has reached equilibrium after several days of drainage water. Field capacity depends on the texture and the amount of organic material. As water content, field capacity and permanent wilting point are defined on a volume of water per volume of soil base. The water available for evapotranspiration after draining (or the available capacity of water retention) is then defined as the field capacity minus wilting point. This value is typically expressed in mm, and can be obtained by integrating the available capacity of retention of water on the actual depth of the soil layer. A large water-holding capacity implies a large annual evapotranspiration and annual runoff small relative to the small water-holding capacity under the same-climatic conditions.

1.5.11. Coefficient of reservoir (*f*)

Runoff is generated from the surplus at a specified rate (***f***, coefficient of reservoir). The coefficient of reservoir, ***f***, determines the fraction of surplus that is transformed in runoff in a month. The remaining surplus is carried over to the following month to compute total **S** (Surplus) for that month. Direct runoff, in millimeters, is added directly to the runoff generated from surplus to compute total monthly runoff in millimeters.

1.6. Drought

The droughts are a natural occurrence associated mainly to a decrease of precipitation, which occurs every year in various regions of the world. Unlike other natural disasters, which usually act quickly and with immediate impacts, drought is a natural disaster of meteorological and climatological origin it is not only more complex disaster as well as it affects more people than any other.

Figure 9- Drought (Inthecapital, 2012)

The impacts resulting from this phenomenon vary according to a spatial and temporal scale. Long periods of drought cause serious economic losses, especially in terms of agriculture, animal production and water resources, often are resulting in the development and spread of pests particularly in countries with weak economies. It also leads to food shortages and consequently to loss a significant number of human lives

While it is a natural disaster that cannot be prevented, its impacts can be minimized by moving large amounts of water or by encouraging the establishment of mechanisms for storage, for its part, bad management of land use and inappropriate farm practices contribute to the degradation of soil and water resources, and increases the vulnerability of populations to drought events.

The problem of drought should be classified under the general circulation anomalies of atmosphere, corresponding to weather fluctuations in local or regional scale. The geographical situation of mainland Portugal is favorable to the occurrence of dry episodes, often associated with blocking situations in which the North Atlantic subtropical anticyclone remains in a position that prevents the perturbations of the polar front reaching the Iberian Peninsula.

1.6.1. Water shortage

The water is becoming scarce not only in arid and drought prone, but also in areas where rainfall is relatively abundant. The shortage is now seen from the perspective of the quantities available for economic and social uses, as well as in relation to water requirements for natural and artificial ecosystems. The concept of scarcity also embraces water quality because many times the available water resources are degraded or only marginally available for use in human and natural systems (Pereira, Cordery, & Iacovides, Coping with Water Scarcity, 2002).

Worldwide, agriculture is the sector that has the highest water requirement. As a result of its large use in agriculture, irrigation is often considered the main cause of water shortage. Irrigation is considered as a poor use of water to produce excessive waste and degrade their quality. However, irrigation in agriculture provides the means of subsistence for a large part of the population of rural areas and yet a large part of foods from all around the world. Nowadays, agriculture irrigation is largely affected by water scarcity. There are efforts by financial agencies and administrators to set up incentives for innovating and improve water management practices to control the negative impacts of irrigation, to diversify the use of water in irrigation projects, and to increase productivity. Meanwhile, great progress in engineering and economic management is producing new considerations for water use and quality control of water for non-agricultural purposes, particularly for domestic use and sanitation services (Pereira, Cordery, & Iacovides, Coping with Water Scarcity, 2002).

Water shortages can result from a wide range of phenomena that can be due to natural causes, induced by human activities, or request result from the interaction of both as indicated in Table

Water shortage	**Natural**	**Human origin**
Permanent	*Aridity*	*Desertification*
Temporary	*Drought*	*Water penury*

Table 3 - Classification of water shortages

Aridity is natural imbalance permanently available water consisting of a low average annual precipitation, with high spatial and temporal variability, resulting in an overall low humidity and reduced carrying capacity of ecosystems. (Pereira, Cordery, & Iacovides, Coping with Water Scarcity, 2002)

Drought is a natural imbalance of available water that is based on a lower than average rainfall. Has frequency, duration and severity uncertain and unpredictable occurrence and results in a diminution of water resources available. (Pereira, Cordery, & Iacovides, Coping with Water Scarcity, 2002)

Desertification is an imbalance of available water in arid and sub-humid regions due to land degradation, particularly the over-exploitation of groundwater and / or surface water, soil degradation, erosion, inappropriate land use, reduced infiltration, floods faster and loss of riparian ecosystems

<u>Water penury</u> is an imbalance in the available water including overexploitation of aquifers, reducing reservoirs capacity, inappropriate land use, degradation of water quality and reduction of carrying capacity of ecosystems (Pereira, Cordery, & Iacovides, Coping with Water Scarcity, 2002)

1.6.2. Drought definitions

Drought is a continued period of anomalous dry weather having a great impact in causing problems in agriculture, animal production and / or water supply. Figure 10 explains the evolution of drought with the time.

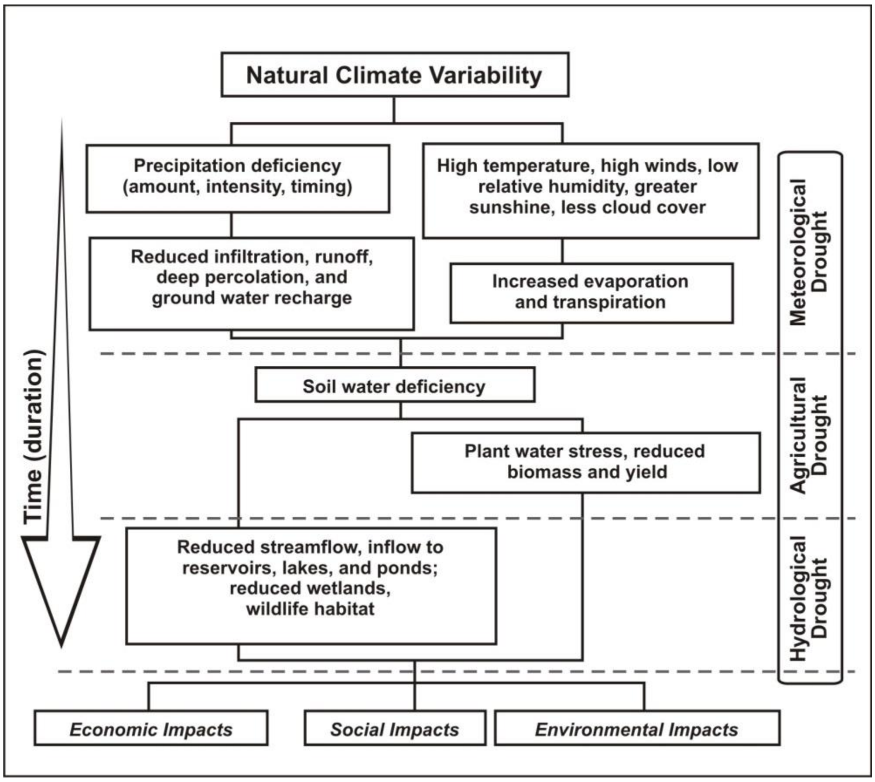


Figure 10 - Drought definitions (National Drought Mitigation Center)

1.6.3. Meteorological drought

The meteorological drought is a measure of the deviation of precipitation in relation to the normal value, characterized by water shortages induced by the imbalance between precipitation and evaporation, which depends on other factors such as wind speed, air temperature and humidity, insolation. The definition of dry weather must be considered depending on the region, since the atmospheric conditions that result in deficiencies of precipitation can be very different from region to region.

1.6.4. Agriculture drought

The agricultural drought is associated with water shortages caused by the imbalance between the available soil water, the need of crops and plant transpiration. This type therefore being associated with drought crop characteristics, the natural vegetation, or agricultural systems in general.

1.6.5. Hydrological drought

The hydrological drought is related to the median reduction of water in the reservoir and the soil's water depletion. This type of drought occurs after the meteorological and agriculture drought, since a longer time is required for the precipitation deficiencies to manifest themselves in various components of water systems.

1.6.6. Socio-economic drought

The socio-economic drought is associated with the combined effect of natural and social impacts that result from water shortage, due to the imbalance between the supply and demand of water resources affecting directly populations.

1.6.7. Drought estimation

The amount and distribution of annual rainfall, and high values of air temperature, are conditions that determine the intensity and consequences of a drought. In order to estimate the possibility of a drought, or its severity, one must know the weather conditions.

Meteorological data that are more important to know are, for example, the precipitation, air temperature, air humidity and water content in the soil.

The effects of droughts can be immediately felt in agriculture, because it is directly dependent of the water storage in soil, where other activities may only be subsequently affected since they can depend on superficial reserves. Generally, the activities that depend on groundwater reserves are the last to be affected. When normal conditions are restored, the water replacement is done in reverse: first the water reserves in the soil, followed by the flow of watercourses and reservoirs and lakes and finally groundwater. The recovery time is dependent on the duration and severity of dry and precipitation checked after it's finished.

1.6.8. Standard Precipitation Index (SPI)

The **SPI** (Standard Precipitation Index) is an index developed by Mckee, Doesken, & Kleist (1993) in order to set and monitoring local droughts and it was designed also to identify droughts in different timescales. Although it has been designed to identify drought periods it can also be used in the identification of humid periods. The analyzed scales are usually monthly (**SPI**-1 month) and seasonal or trimestral (**SPI**, 3 months), although also calculate annual SPI (**SPI**-12 months). Different timescales reflect the delay in the response of different resources water anomalies of precipitation. As the time scale increases, SPI response becomes slower to precipitation changes.

The **SPI** is calculated based on the probability distribution of rainfall for the period chosen. Thus, the **SPI** index values obtained depend on the distribution function chosen from the sample values from which the parameters are determined from the distribution, and also the estimation method. The **SPI** allows comparisons between different locations and different periods of time due to the fact that this index indicates the distance between the observed precipitation and average for a given month, and also be normalized by the standard deviation of the precipitation site of the month.

The **SPI** calculated in this way has the following characteristics (Mckee, Doesken, & Kleist, 1993)

- **SPI** is uniquely related to the probability;
- Precipitation used in the **SPI** can be used to calculate the deficit precipitation for the period used;
- Precipitation used in the **SPI** can be used to calculate the current percentage of the average rainfall for the time period k months;
- **SPI** is normally distributed and therefore can be used to monitoring dry periods as humid periods;
- **SPI** is normalized, so dry and wet periods are represented in similar ways.

1.6.9. Palmer Drought Standard Index (PDSI)

The **PDSI** is a meteorological drought index, and it responds to weather conditions that have been unusually dry or unusually wet. When conditions change from dry to normal or wet, for example the drought measured by the **PDSI** ends without taking into account streamflow, lake and reservoir levels, and other longer-term hydrologic impacts (Karl & Knight, 1985). The **PDSI** is calculated based on precipitation and temperature data, as well as the local Available Water Content – **AWC** – of the soil. From the inputs, all the basic terms of water balance equation can be determined, including evapotranspiration, soil recharge, runoff and moisture loss from the surface. Human impacts on the water balance, such as irrigation, are not considerate.

1.7. Cultural coefficient (K_c)

According to Doorenbos & Pruitt (1977), a crop evapotranspiration (**ET_c**) can be calculated from the reference evapotranspiration (**ET_o**) and crop coefficient (**K_c**) at different growth stages. **ET_o** is the evapotranspiration of a hypothetical culture, actively growing, without limitation water and expresses the evaporating power of the atmosphere at a specific temporal and spatial scale, without considering the characteristics of the soil and crop. Allen, Pereira, Raes, & Smith, (1998) recommended the use of the Penman-Monteith equation with some simplifications, also known as the FAO Penman-Monteith method as the standard method for estimating the $\mathbf{ET_o}$ from climatic data.

The crop coefficient ($\mathbf{K_c}$) is experimentally obtained relationship between $\mathbf{ET_c}$ and $\mathbf{ET_o}$, and represents the integration of the effects of four characteristics that distinguish the crop evapotranspiration of reference evapotranspiration: the height of culture, the resistance of the canopy, the albedo of the soil surface cultivation, and water evaporation on the soil surface (Pereira & Allen, Novas aproximações aos coeficientes culturais, 1997).

2. METHODS

2.1. Study area

Portugal is located in southwestern Europe, on the Iberian Peninsula, between latitudes 37º and 42º N, in the transitional climatic region between the sub-tropical anticyclone and the sub-polar depression zones. Portugal's climate is Mediterranean, with strong north-south and west-east climatic variability. Mean annual temperature values vary between 7ºC in the inner highlands of central Portugal and 18º C in the southern coastal region. Mean monthly air temperature values have a distinct pattern during the year, reaching their maximum in August and minimum in January. Mean annual precipitation in mainland Portugal is around 900 mm, with the highest values (above 3000 mm) in the highlands of the northwest region and the lowest values (around 500 mm) in the southern coast and in the eastern part of the territory (below or around 500 mm). On average, about 42% of annual precipitation falls during the 3-month winter season (December-February) and the lowest values occur during summer (June-August), corresponding to only 6% of annual precipitation, as it is characteristic of Mediterranean climates. (Rego, Acácio, Van Lanen, & Stahl, 2013)

2.1.1. Dataset

We selected the meteorological stations with the longest and most complete dataset of monthly precipitation across a north-south gradient in Portugal. Precipitation data was obtained from the Portuguese Meteorological Service (Institute of Meteorology). Characteristics of the selected meteorological stations and the precipitation dataset are provided in Table 4.

Gauging stations (table 5) with monthly streamflow data were selected based on the following simultaneous criteria:

- Proximity to one of the selected meteorological stations (maximum distance: approximately 100 km);
- Near-natural streamflow (disturbances as low as possible during the period of time selected), with no overt adjustment of “natural” streamflow, such as flow diversion or augmentation, regulation of the streamflow by some flow-reducing structure (e.g. dam or weir), or reduction of base flow by extreme groundwater pumping;
- Catchment area not too large (< 1000 km^2);
- Long and complete time series of recorded monthly streamflow (minimum 30 years and no more than 10% of values missing during the period of record).

These were compared with metadata on regulation and catchment area from the national streamflow database (table 6) - the National Information System on Hydric Resources (SNIRH), a public dataset provided by the Portuguese Water Institute (INAG/APA). The quality and length of the data series was highly variable and most of the 416 stations had short-term or incomplete data series and regulation. An initial group of 32 gauging stations was selected to go through quality control, including detection of visible inhomogeneities or mislabelled missing values (e.g. zeros). After a final quality check, five stations were selected for analysis (table 4). The selected stations cover a north-south climatic gradient in mainland Portugal (table 4). Stations located in Douro basin, northern Portugal, show higher streamflow values than stations located in Tejo and Guadiana basins, southern Portugal. Streamflow is higher than precipitation (2067 and 1905 mm, respectively) for the pair of meteorological-gauging stations Coimbra–Manteigas because the catchment drained by the Manteigas gauging station is at higher altitude than the Coimbra rain gauge. A more nearby rain gauge at the same altitude than the Manteigas gauging station with sufficient long record was not available. For each station, monthly volumetric discharge (L^3, dam^3) was transformed into monthly streamflow (mm) by dividing the volumetric discharge by the catchments area (L^2, km^2).

Watershed characterization

River Basin	Gauging Station	Catchment drainage area (km^2)	Annual precipitation (mm)	Average Catchment Altitude (m)	Monthly Streamflow Data period	Length (n. years)	Anual Mean (mm)	Anual Median (mm)	Closest Meteorological station with long-term data (km)
Douro	**Gimonde**	405,6	861	804	1967-2004	38	510	467	Bragança (14.6)
	Vale Giestoso	77,7	1334	917	1958-1990	33	766	641	Porto (96)
Tejo	**Manteigas**	27,4	1905	1520	1949-1996	48	2067	1944	Coimbra (78.8)
	Pavia	616,6	622	265	1953-1989	37	132	98	Lisboa (103.5)
Guadiana	**Vascão**	409,9	667	291	1961-2011	51	217	189	Beja (59.7)

Table 4 - Characterization of selected meteorological stations and precipitation dataset

Meteorological Station	Latitude (ºN)	Longitude (ºW)	Altitude (m)	Available Data period	Mean Annual Precipitation (mm)	Annual Precipitation Standard Deviation (mm)
Bragança	41° 48´	6° 44´	690	1945-2011	708	199
Porto	41° 08´	8° 36´	93	1864-2011	1209	307
Coimbra	40° 12´	8° 25´	141	1866-2011	946	215
Lisboa	38° 43´	9° 09´	77	1864-2011	720	197
Beja	38° 01´	7° 52´	246	1941-2011	543	171

Table 5 - Characterization of selected gauging stations and streamflow dataset

Gauging Station	Own drained area (km^2)	Average altitude of drained area (m)	Average slope	Average number of flows	Maximum retention	Total annual rainfall (mm)
Gimonde	405,6	803,66	0,159	77,082	32,835	861
Vale Giestoso	77,722	916,85	0,112	76,207	34,479	1334
Manteigas	27,405	1519,49	0,329	86,118	17,802	1905
Pavia	616,634	264,76	0,055	78,849	29,623	622
Vascão	409,894	291,03	0,106	73,677	39,456	667

Table 6 - Portuguese Meteorological Service (Institute of Meteorology) dataset information of watersheds

2.1.2. Geographic location

The figure 11 represents the geographical location of studied watersheds and gauging stations. The latitude of gauging stations ranges from 38° 01´ (Gimonde, Bragança) to 41° 48´ (Vascão, Beja).

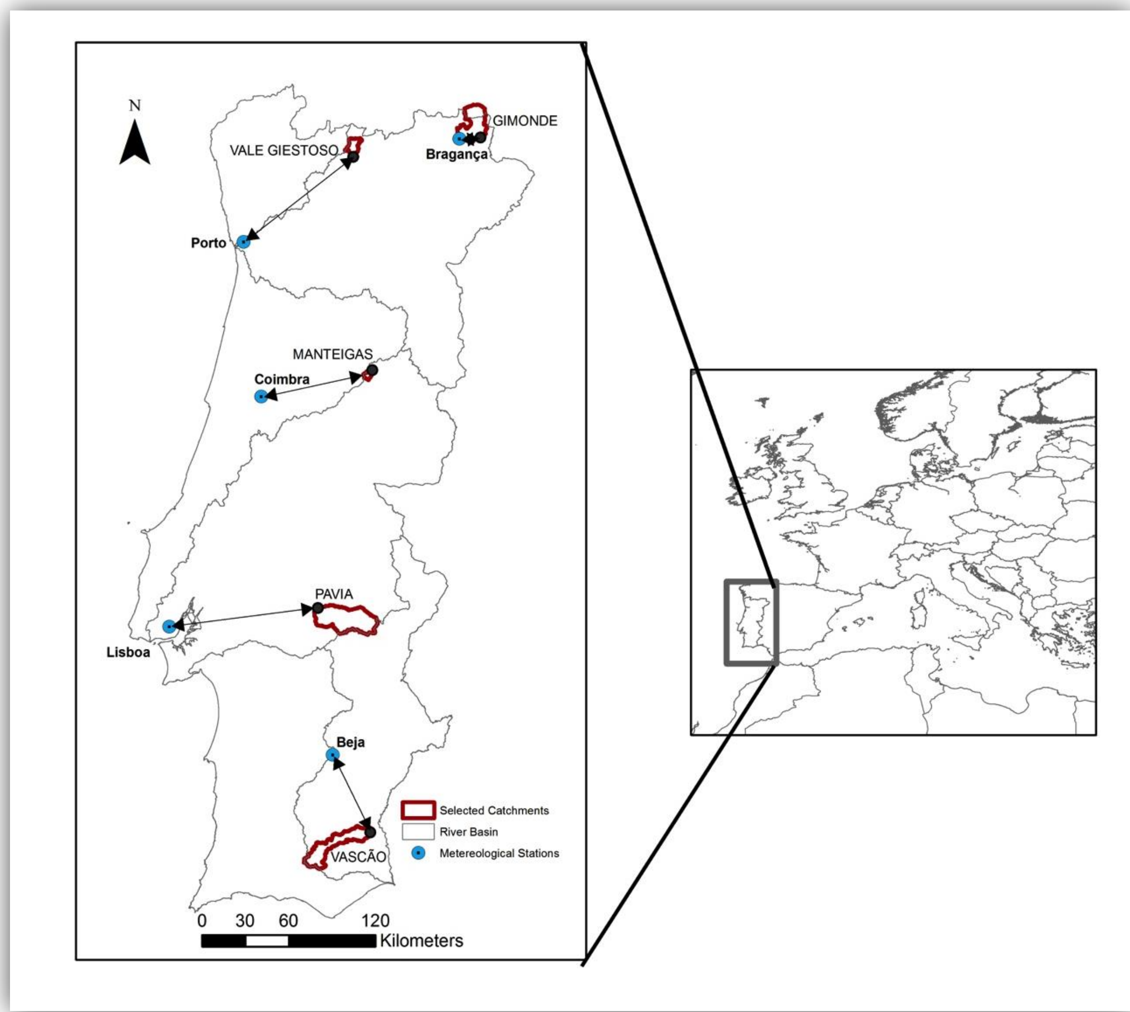


Figure 11 - Location of selected catchments and meteorological stations (Rego, Acácio, Van Lanen, & Stahl, 2013)

2.2. Thornthwaite-mather method

The use of Thornthwaite-Mather model associated with the need of use, firstly, a minimum number of temporal and spatial inputs as precipitation, temperature and latitude. By other side the need of use an acceptable and known model for the other partners of Drought R&SPI project. Although there are known limitations in the Thorthwaite - Mather model , like all simple models , this has less adhesion to concrete realities that need models with calibration parameters . However, for the first exploration selection of this model keeps justifiable. Other model that can be used was The Penman-Monteith combination equation that is used to estimate the rate of moisture transport away from a surface.

2.3. Trends in annual precipitation and streamflow

Trends in annual precipitation and streamflow in selected periods for all watersheds based on pairs of meteorological and gauging stations. The solid line represents the trend line of the variations in precipitation and actual flow obtained from Portuguese Meteological Service.

2.4. Analysis of coefficient of reservoir (f) and available water capacity (AWC)

For the determination of the value of **AWC** (Available Water Capacity) and the value of ***f*** (coefficient of reservoir) studies were performed based on data of land use with which we are working (1970, 1990, 2000 and 2006, respectively). To determine these values, we proceeded to the interpretation of data from Thornthwaite-Mather model. The values of "*runoff*" (calculed by precipitation and temperature in Thornthwaite-Mather model) and the value of "*actual flow*" (data obtained from Portuguese Meteorological Service, Institute of Meteorology) are then compared. The objective of the study is to search **AWC** values (Available Water Capacity) as well as ***f*** values (coefficient of reservoir) for which the value of the correlations in the intervals determined by matrices of land use is closest to unit value. For time intervals, the values determined are shown in the tables below. To prove that the correlations are reliable, graphics have been done to prove that the values obtained are real.

2.5. Land use

Table 7 - (CORINE Land Cover (CLC) nomenclature)

Level 1	Level 2	Level 3
1 Artificial surfaces	11 Urban fabric	111 Continuous urban fabric
		112 Discontinuous urban fabric
	12 Industrial, commercial and transport units	121 Industrial or commercial units
		122 Road and rail networks and associated land
		123 Port areas
		124 Airports
	13 Mine, dump and construction sites	131 Mineral extraction sites
		132 Dump sites
		133 Construction sites
	14 Artificial, non-agricultural vegetated areas	141 Green urban areas
		142 Sport and leisure facilities
2 Agricultural areas	21 Arable land	211 Non-irrigated arable land
		212 Permanently irrigated land
		213 Rice fields
	22 Permanent crops	221 Vineyards
		222 Fruit trees and berry plantations
		223 Olive groves
	23 Pastures	231 Pastures
	24 Heterogeneous agricultural areas	241 Annual crops associated with permanent crops
		242 Complex cultivation patterns
		243 Land principally occupied by agriculture, with significant areas of natural vegetation
		244 Agro-forestry areas
3 Forest and semi natural areas	31 Forests	311 Broad-leaved forest
		312 Coniferous forest
		313 Mixed forest
	32 Scrub and/or herbaceous vegetation associations	321 Natural grasslands
		322 Moors and heathland
		323 Sclerophyllous vegetation
		324 Transitional woodland-shrub
	33 Open spaces with little or no vegetation	331 Beaches, dunes, sands
		332 Bare rocks
		333 Sparsely vegetated areas
		334 Burnt areas
		335 Glaciers and perpetual snow
4 Wetlands	41 Inland wetlands	411 Inland marshes
		412 Peat bogs
	42 Maritime wetlands	421 Salt marshes
		422 Salines
		423 Intertidal flats
5 Water bodies	51 Inland waters	511 Water courses
		512 Water bodies
	52 Marine waters	521 Coastal lagoons
		522 Estuaries
		523 Sea and ocean

In 1985 the CORINE program was initiated in the European Union. CORINE means 'coordination of information on the environment' and it was a prototype project working on many different environmental issues. The CORINE databases and several of its programs have been taken over by the European Environmental Agency. One of these is an inventory of land cover in 44 classes, and presented as a cartographic product, at a scale of 1:100 000. This database is operationally available for most areas of Europe and is shown on table 7. (http://www.eea.europa.eu/) (Commission of the European Communities , 2005).

Analysis of the land-use used the CORINE-nomenclature. In order to divide the land-use into classes.

In this project, to be able to approximate the CORINE legend to analyze the data, it was decided to create a new legend that grouped all the data in order to obtain data more easy to study. The grouped data as shown in table 7, was regrouped to:

1. Agricultural and urban areas, including all artificial surfaces and agricultural areas (excluding 244, agroforestry system)
2. Agroforestry system, 244 in CORINE legend.
3. Broadleaved forests, 311 in CORINE legend.
4. Mixed and coniferous forest, 312 and 313 in CORINE legend respectively.
5. Bushes and other, for all semi natural areas (excluding forests), wetlands and water bodies.

The used data was obtained from IFN (National Forest Inventory) and COS (Soil Occupation Map) and are used data from 1970, 1990, 2000 and 2006. The data obtained are in the form of level 3 of the CORINE legend and will be converted to the new class created.

2.6. Drought analysis

2.6.1. Standard Precipitation Index - SPI

To calculate the **SPI**, a probability density function, it has to adequately describe the data. The distribution function was selected to fit the rainfall data from each study station. The **SPI** is an output count and a state of the medium and it is expressed in units of standard deviation. The **SPI** is an index to a temporal and spatial scale. The values of the **SPI** can be classified according to classes. The **SPI** is an index at a temporal and spatial scale. The values of the **SPI** can be classified according to classes. In this study, the class is established almost normal from the aggregation of five classes: -3 <**SPI** <-1.5 (extreme drought) = value 4; -1.5 <**SPI** <-1 (severe drought) = value 3; -1 <**SPI** <-0.5 (moderate drought) = value 2; -0.5 <**SPI** <0 (mild drought) = value 1; and **SPI**> 0 (no drought) = value 0, expressed in the table 34. The output data are a probability indication or severity of dry/humidity that can be used for risk assessment. The time series of SPI can be used for drought monitoring, setting specific limits for implementing **SPI** for defining drought beginning and ending many times. The accumulated values of the **SPI** can be used to analyze the severity drought. In this study, the program developed SPI_SL_6 by National Drought Mitigation Centre, University of Nebraska-Lincoln and was used to calculate time series of drought indices (**SPI**) for each station in the basin and for each month of the year, in one time scale. In each sub-basin, for each station, we used the values of **SPI** to 12 months. **SPI**-12 computed reflects long terms precipitation patterns. **SPI**-12 is a comparison of rainfall for 12 consecutive months with the same 12 consecutive months of all previous years of data available and is a good indicator of drought conditions in the long term. This time scale is the cumulative result of shorter periods that may be above or below normal, the longer the **SPI** approach zero unless a specific trend is occurring.

The monthly **SPI** values range in a continuous interval. That is a continuous dependent variable (**SPI**) of an independent variable discontinuous (month). Once the **SPI** values are obtained in view of the annual cycles of the average and standard deviation of monthly precipitation, it was assumed that the time series of **SPI** are a realization of a process, assuming no climate trends. Throughout the series it exists periods of months where **SPI** < -1 (moderated and slight). The drought begins when we've a period of **SPI** < 1 and it finishes when we've **SPI** > -1. Each drought has certain month duration **DL**, in months, and a average magnitude **DMM** (The average value of **SPI** in that **DL** period). The drought magnitude is the **DM**, expressed in SPI/month.

2.6.2. Palmer Drought Severity Index

Although Palmer Drought Severity Index – **PDSI** - is sufficiently viable in this project as well as throughout the DROUGHT project, it opted for a simpler index, as Standard Precipitation Index – **SPI** - and it just takes into account precipitation data.

2.7. SCS curve number

The runoff curve number, **CN**, is a parameter used to predict runoff from rainfall excess. The curve number method, **CN**, was developed by the USDA-SCS (1985), which was called the Soil Conservation Service or SCS. The runoff curve number was developed from an analysis of runoff. It is an efficient method widely used for determining the approximate amount of direct runoff from a rainfall event in a particular area.

The runoff curve number uses hydrologic soil group, land use, hydrologic condition and treatment. References, such as from USDA-SCS (1985) indicate the runoff curve numbers for characteristic land cover descriptions and a hydrologic soil group.

Curve number (**CN**) is a representation of potential maximum soil retention, S (Ponce & Hawkins, 1996).

$$Q = \frac{(P - 0{,}2\,S)^2}{(P + 0{,}8\,S)}$$

Where,

Q is runoff

P is rainfall

S is the potential maximum soil moisture retention after runoff begins

The runoff curve number, **CN**, is then related

$$S = \frac{1000}{CN} - 10$$

Curve Number, **CN**, has a range from 30 to 100; lower numbers indicate low runoff potential while larger numbers are for increasing runoff potential. The values are described by (USDA-SCS, 1985).

Curve numbers are shown in tables 8, 9, 10 and 11.

Cover description: Cover type and hydrologic condition	Average percent impervious area [2]	Curve numbers for hydrologic soil group: A	B	C	D
Fully developed urban areas (vegetation established)					
Open space (lawns, parks, golf courses, cemeteries, etc.) [3]:					
Poor condition (grass cover < 50%)		68	79	86	89
Fair condition (grass cover 50% to 75%)		49	69	79	84
Good condition (grass cover > 75%)		39	61	74	80
Impervious areas:					
Paved parking lots, roofs, driveways, etc. (excluding right-of-way)		98	98	98	98
Streets and roads:					
Paved; curbs and storm sewers (excluding right-of-way)		98	98	98	98
Paved; open ditches (including right-of-way)		83	89	92	93
Gravel (including right-of-way)		76	85	89	91
Dirt (including right-of-way)		72	82	87	89
Western desert urban areas:					
Natural desert landscaping (pervious areas only) [4]		63	77	85	88
Artificial desert landscaping (impervious weed barrier, desert shrub with 1- to 2-inch sand or gravel mulch and basin borders)		96	96	96	96
Urban districts:					
Commercial and business	85	89	92	94	95
Industrial	72	81	88	91	93
Residential districts by average lot size:					
1/8 acre or less (town houses)	65	77	85	90	92
1/4 acre	38	61	75	83	87
1/3 acre	30	57	72	81	86
1/2 acre	25	54	70	80	85
1 acre	20	51	68	79	84
2 acres	12	46	65	77	82
Developing urban areas					
Newly graded areas (pervious areas only, no vegetation) [5]	77	86	91	94	
Idle lands (CN's are determined using cover types similar to those in table 2-2c).					

Table 8 - Runoff curve numbers for urban areas (USDA-SCS, 1985)

Cover description			Curve numbers for hydrologic soil group			
Cover type	Treatment 2/	Hydrologic condition 3/	A	B	C	D
Fallow	Bare soil	—	77	86	91	94
	Crop residue cover (CR)	Poor	76	85	90	93
		Good	74	83	88	90
Row crops	Straight row (SR)	Poor	72	81	88	91
		Good	67	78	85	89
	SR + CR	Poor	71	80	87	90
		Good	64	75	82	85
	Contoured (C)	Poor	70	79	84	88
		Good	65	75	82	86
	C + CR	Poor	69	78	83	87
		Good	64	74	81	85
	Contoured & terraced (C&T)	Poor	66	74	80	82
		Good	62	71	78	81
	C&T+ CR	Poor	65	73	79	81
		Good	61	70	77	80
Small grain	SR	Poor	65	76	84	88
		Good	63	75	83	87
	SR + CR	Poor	64	75	83	86
		Good	60	72	80	84
	C	Poor	63	74	82	85
		Good	61	73	81	84
	C + CR	Poor	62	73	81	84
		Good	60	72	80	83
	C&T	Poor	61	72	79	82
		Good	59	70	78	81
	C&T+ CR	Poor	60	71	78	81
		Good	58	69	77	80
Close-seeded or broadcast legumes or rotation meadow	SR	Poor	66	77	85	89
		Good	58	72	81	85
	C	Poor	64	75	83	85
		Good	55	69	78	83
	C&T	Poor	63	73	80	83
		Good	51	67	76	80

Table 9 - Runoff curve numbers for cultivated agricultural lands (USDA-SCS, 1985)

Cover description		Curve numbers for hydrologic soil group			
Cover type	Hydrologic condition	A	B	C	D
Pasture, grassland, or range—continuous forage for grazing. 2/	Poor	68	79	86	89
	Fair	49	69	79	84
	Good	39	61	74	80
Meadow—continuous grass, protected from grazing and generally mowed for hay.	—	30	58	71	78
Brush—brush-weed-grass mixture with brush the major element. 3/	Poor	48	67	77	83
	Fair	35	56	70	77
	Good	30 4/	48	65	73
Woods—grass combination (orchard or tree farm). 5/	Poor	57	73	82	86
	Fair	43	65	76	82
	Good	32	58	72	79
Woods. 6/	Poor	45	66	77	83
	Fair	36	60	73	79
	Good	30 4/	55	70	77
Farmsteads—buildings, lanes, driveways, and surrounding lots.	—	59	74	82	86

Table 10 - Runoff curve numbers for other agricultural lands (USDA-SCS, 1985)

Cover description		Curve numbers for hydrologic soil group			
Cover type	Hydrologic condition 2/	A 3/	B	C	D
Herbaceous—mixture of grass, weeds, and low-growing brush, with brush the minor element.	Poor		80	87	93
	Fair		71	81	89
	Good		62	74	85
Oak-aspen—mountain brush mixture of oak brush, aspen, mountain mahogany, bitter brush, maple, and other brush.	Poor		66	74	79
	Fair		48	57	63
	Good		30	41	48
Pinyon-juniper—pinyon, juniper, or both; grass understory.	Poor		75	85	89
	Fair		58	73	80
	Good		41	61	71
Sagebrush with grass understory.	Poor		67	80	85
	Fair		51	63	70
	Good		35	47	55
Desert shrub—major plants include saltbush, greasewood, creosotebush, blackbrush, bursage, palo verde, mesquite, and cactus.	Poor	63	77	85	88
	Fair	55	72	81	86
	Good	49	68	79	84

Table 11 - Runoff curve numbers for arid and semiarid rangelands (USDA-SCS, 1985)

3. RESULTS

Tendency ranges of soil proprieties with latitude were analyzed in order to introduce the results. The table 12 shows that the available water capacity tends to lower when the latitude values decrease. The coefficient of reservoir is higher when the latitude is lower. The blue line represents the variation of available water capacity and green line represents the variation of coefficient of reservoir. Available water capacity (**AWC**) tends to decrease and coefficient of reservoir (***f***) tends to increase when the values of latitude decreases.

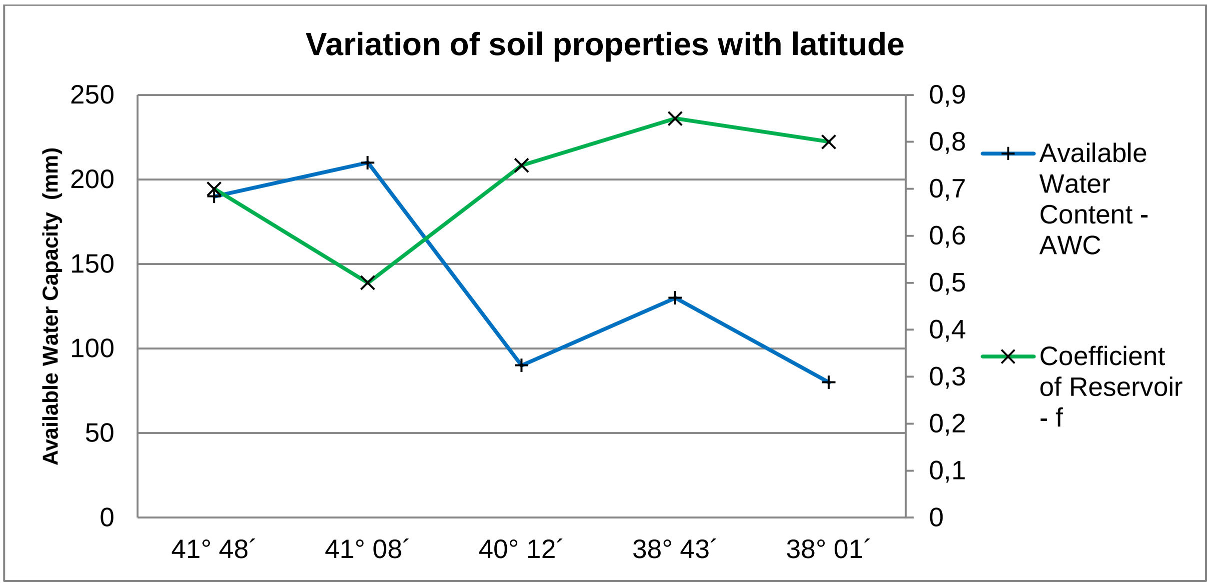


Table 12 - Variation of soil properties with latitude

3.1. Annual Precipitation and Streamflow

The figures below represents the trends for the five paired meteorological and flow gauging stations for the shorter, overlapping period. The sign and magnitude of annual flow trends are consistent with precipitation trends for all stations, except for the pair Gimonde, Bragança, where annual flow and precipitation show opposite trends.

The majority of trends are decreasing; exceptions are small increasing trends observed for Gimonde flow (2,07 mm/year) located in northeast Portugal. The most significant trends in precipitation values was located in Vale Giestoso (-6,74 mm/yr) and Vascão (-6,23 mm/yr). Actual flow has more significant ranges especially in Vale Giestoso (-13,71 mm/yr) and Vascão (-5,14 mm/yr).

We can conclude that system losses a significant amount of water all along the studied period for all the watersheds, by comparing annual average precipitation values with streamflow values.

The table 13, 14, 15, 16 and 17 represents these variations. The values at the right of the graphics are the corresponding estimated trend. The lines with squares/blue represent the average annual precipitation and the lines with rhombus/red, represent the average annual flow. Can also be concluded the closest link between precipitation and real runoff.

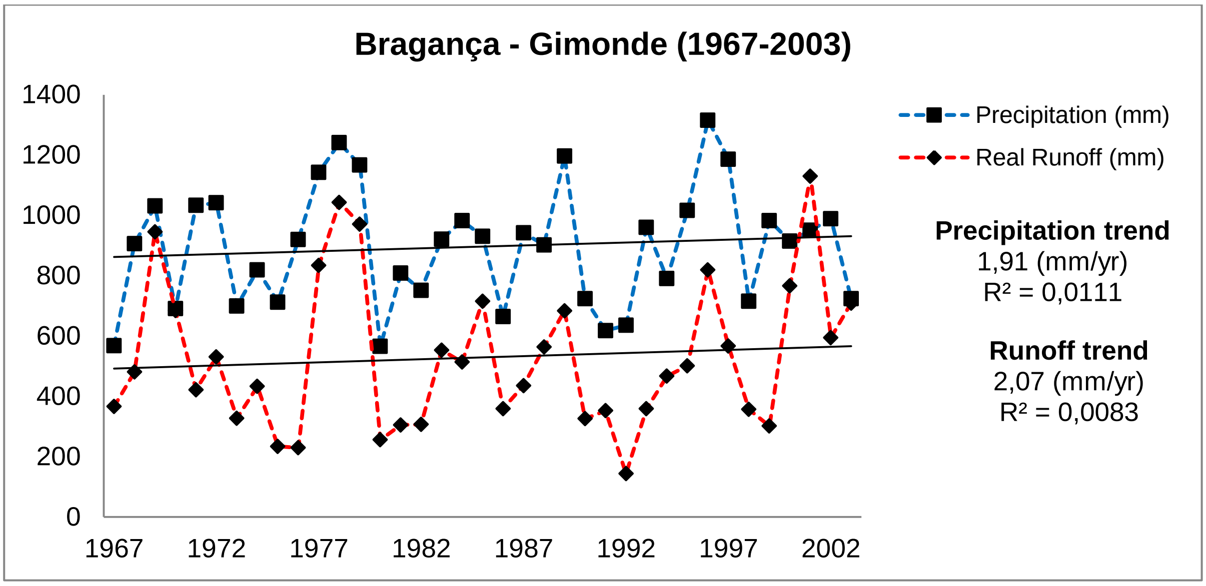


Table 13 - Ranges of average annual precipitation and actual flow in the whole data period in Gimonde, Bragança

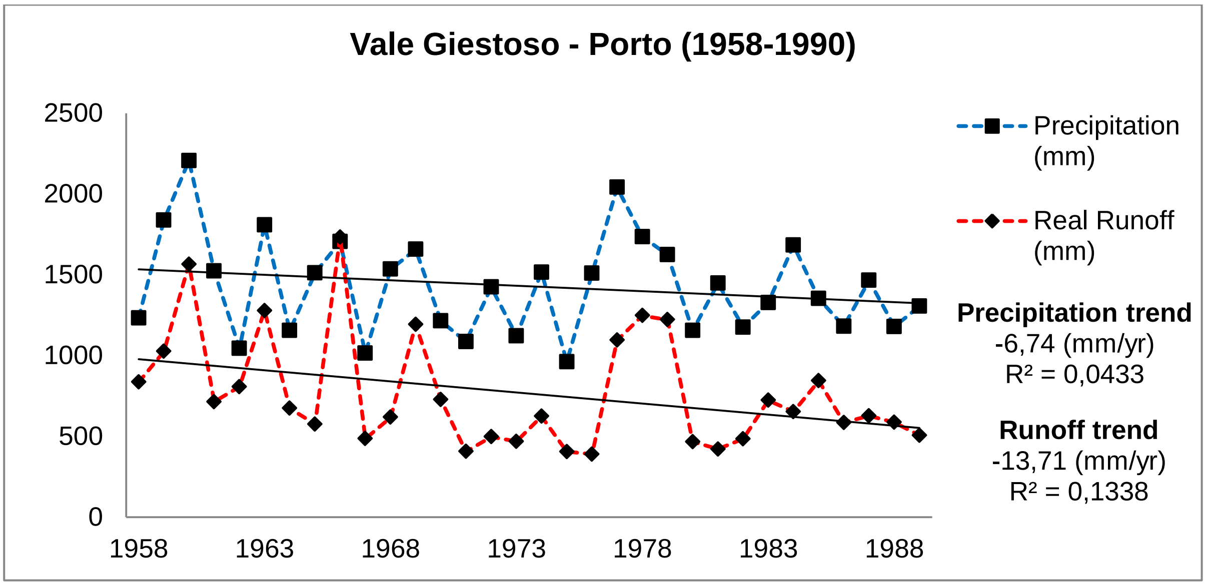


Table 14 - Ranges of average annual precipitation and actual flow in the whole data period in Vale Giestoso, Porto

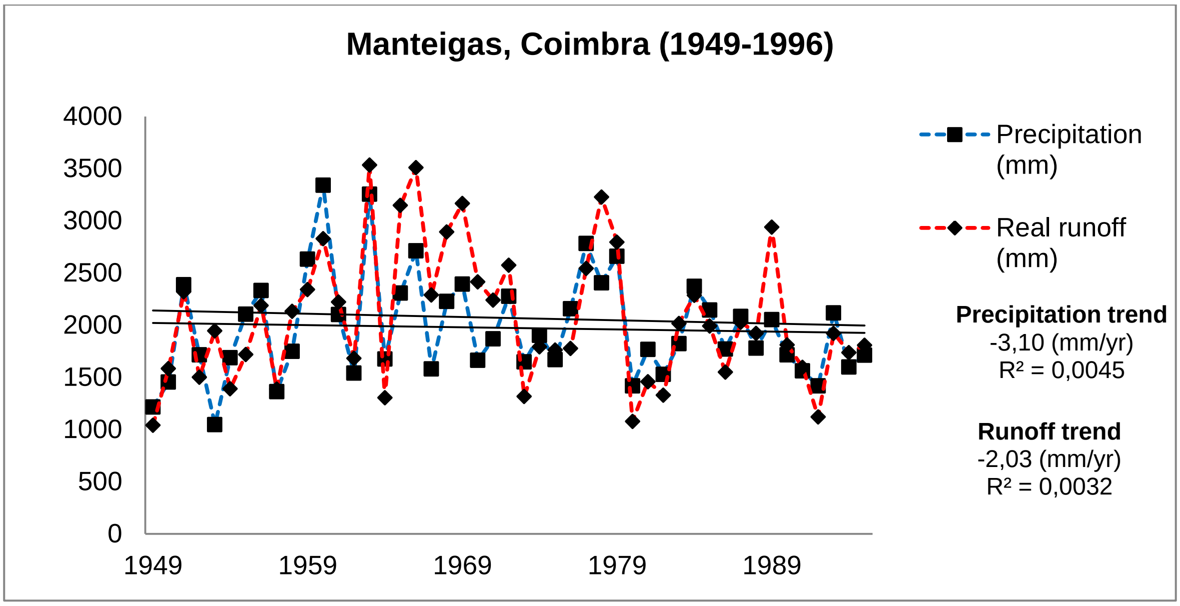


Table 15 - Ranges of average annual precipitation and actual flow in the whole data period in Manteigas, Coimbra.

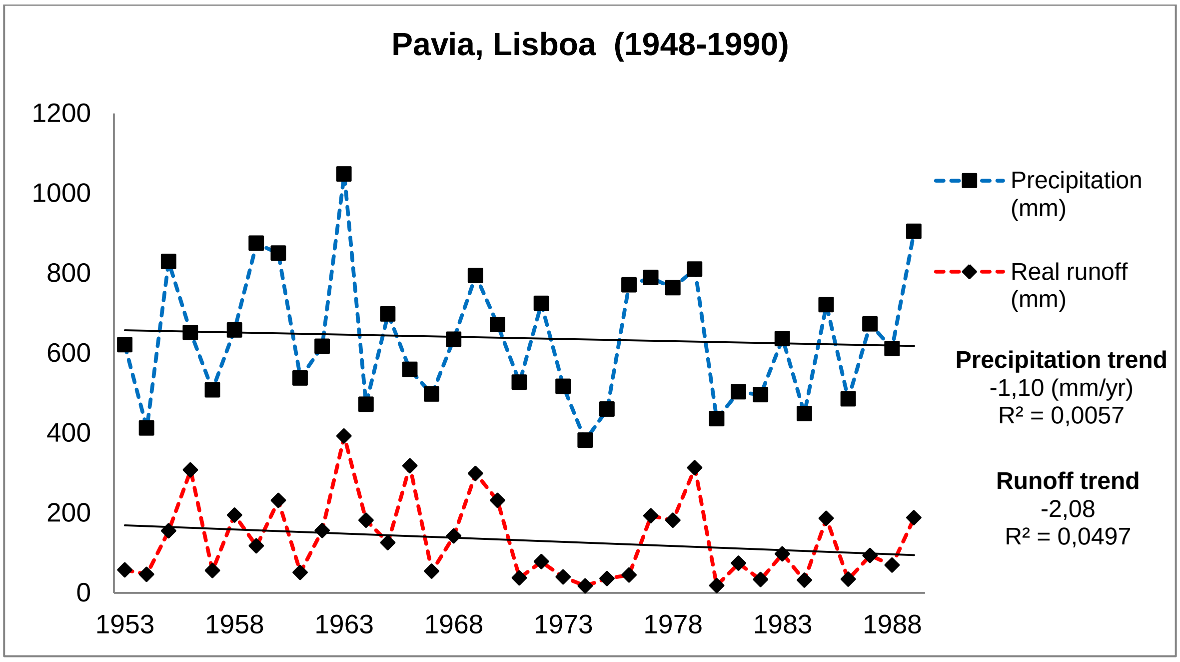


Table 16 - Ranges of average annual precipitation and actual flow in the whole data period in Pavia, Lisboa.

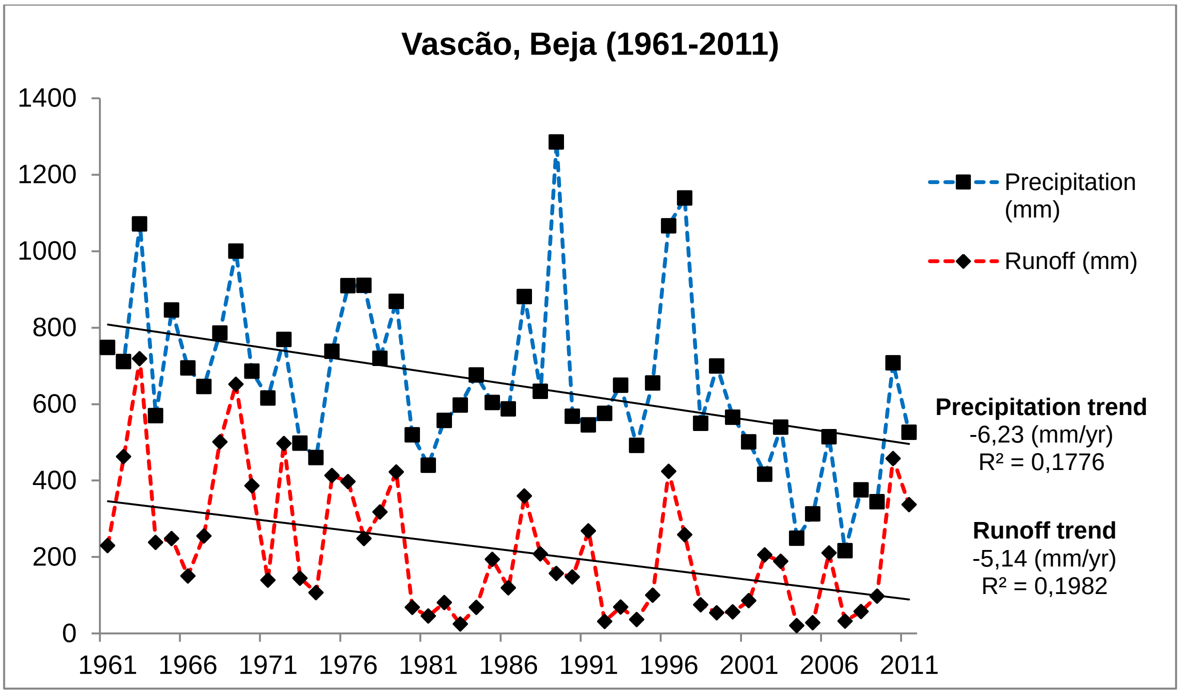


Table 17 - Ranges of average annual precipitation and actual flow in the whole data period in Vascão, Beja.

3.2. Comparison between precipitation and runoff (real and simulated)

Tables 18 to 29 show a comparison between precipitation and runoff (real and simulated). Graphics show a close link between the values calculated and actual flow. The graphics presented showed that it achieves a significant approximation and a tendency to approach the values of runoff and precipitation. It is then possible to approximate the flow values with the values of precipitation, temperature and latitude by using this model. Blue line represents the precipitation, dark green represents the actual runoff and light green represents the computed runoff.

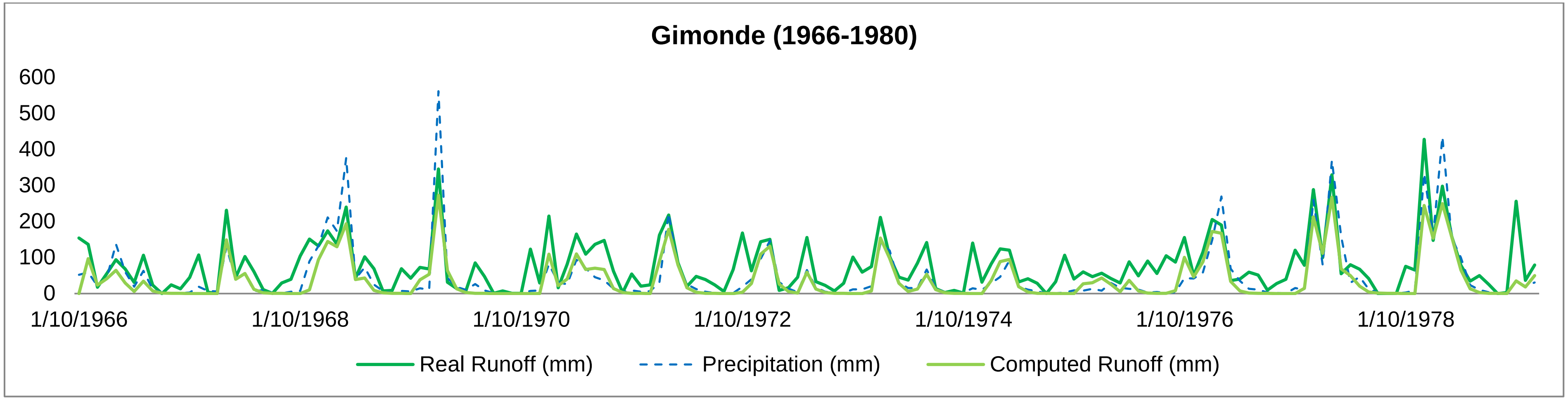


Table 18 – Gimonde, Comparison between precipitation and runoff (real and computer) 1966-1980

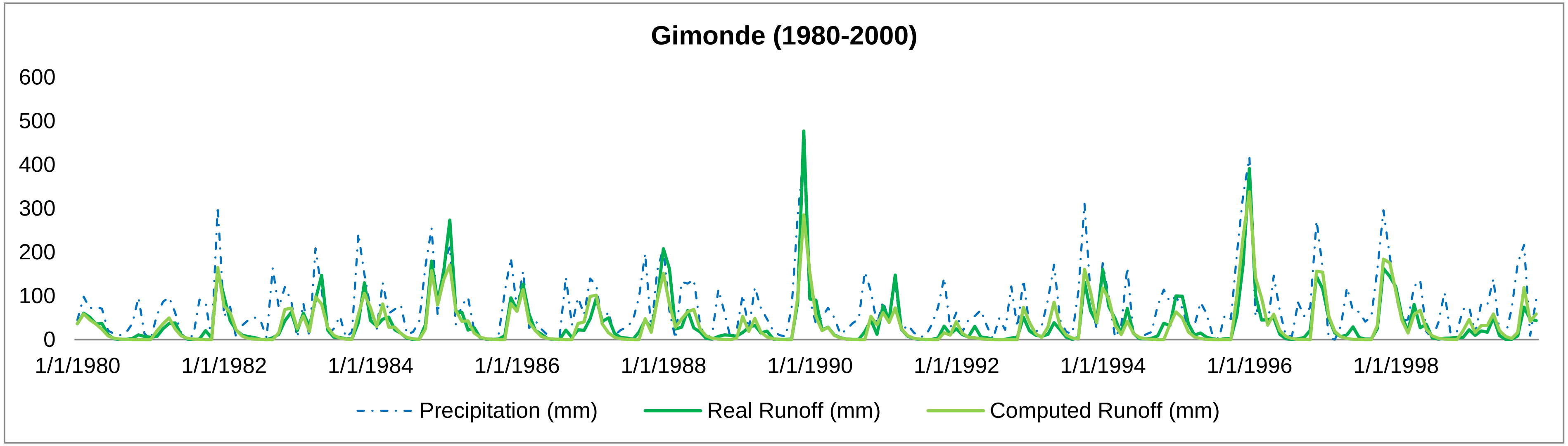


Table 19 – Gimonde, Comparison between precipitation and runoff (real and computer) 1980-2000

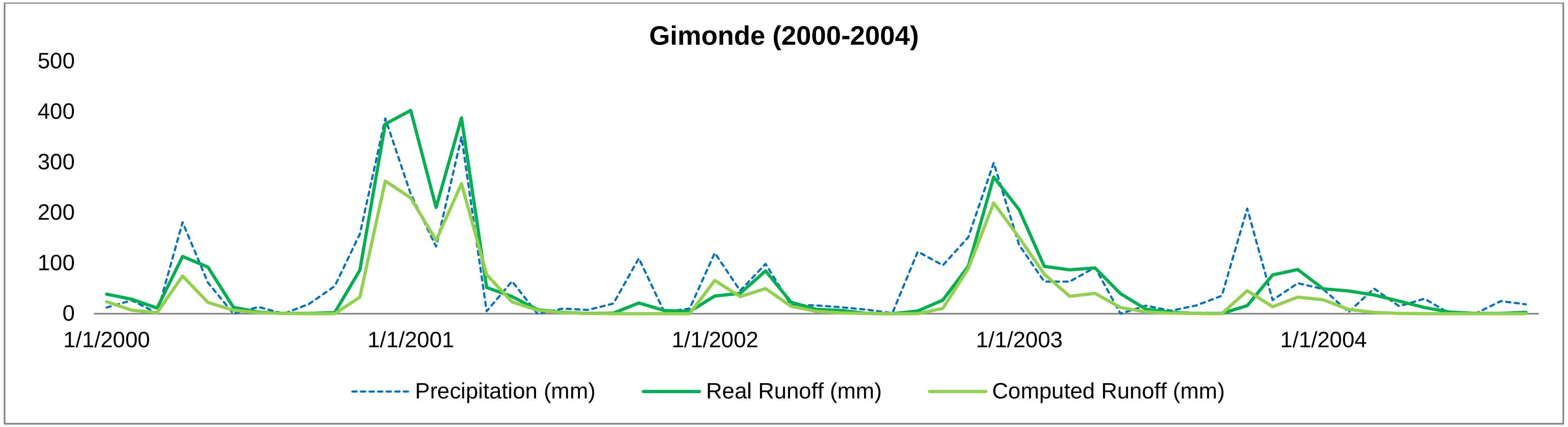


Table 20 - Gimonde, Comparison between precipitation and runoff (real and computed) 2000-2004

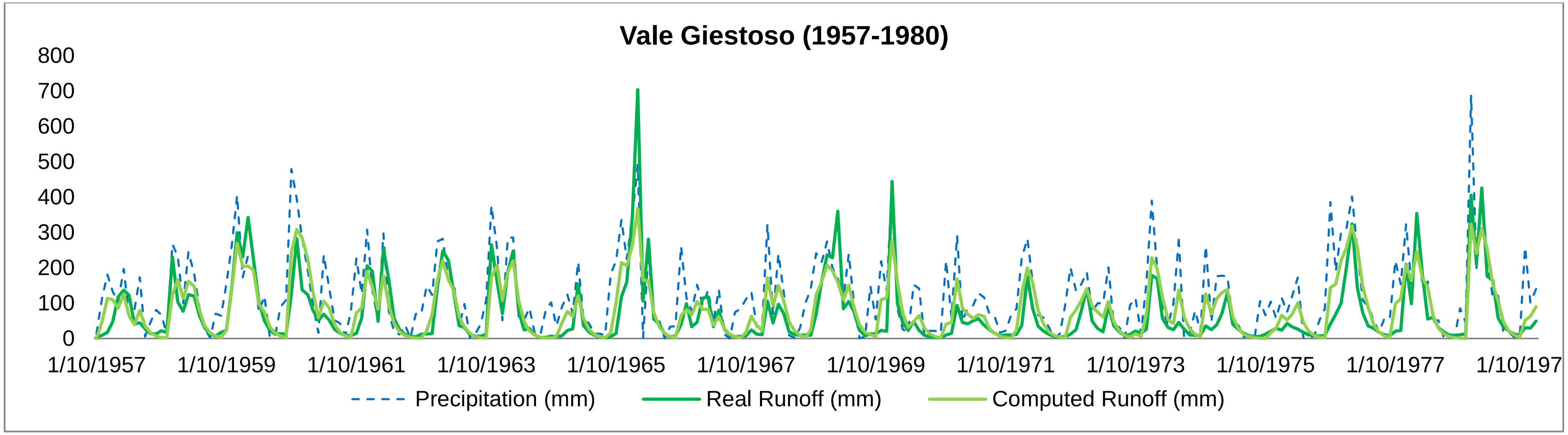


Table 21 - Vale Giestoso, Comparison between precipitation and runoff (real and computed) 1957-1980

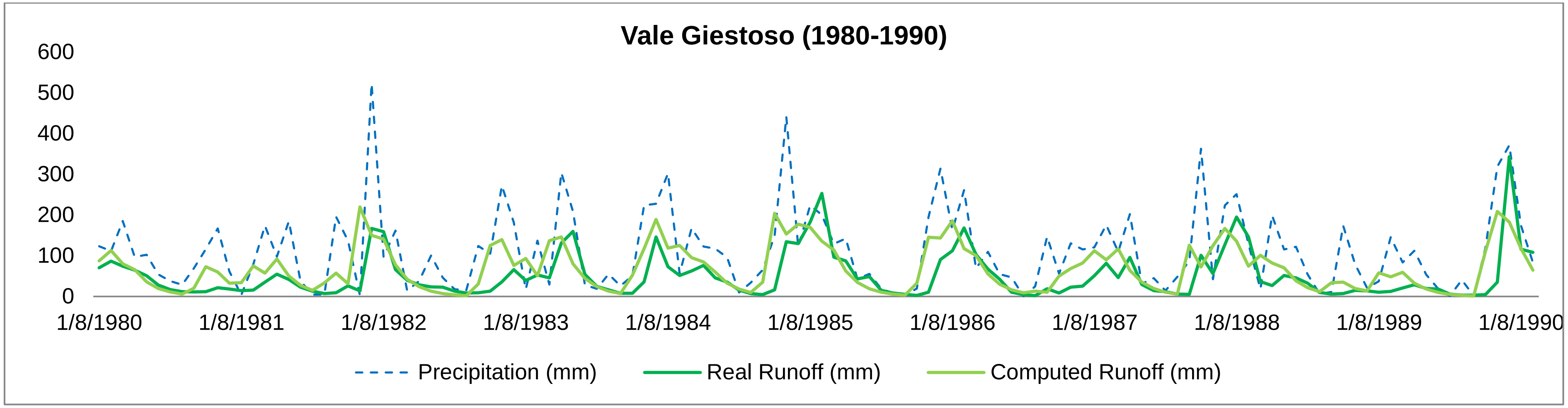


Table 22 - Vale Giestoso, Comparison between precipitation and runoff (real and computed) 1980-1990

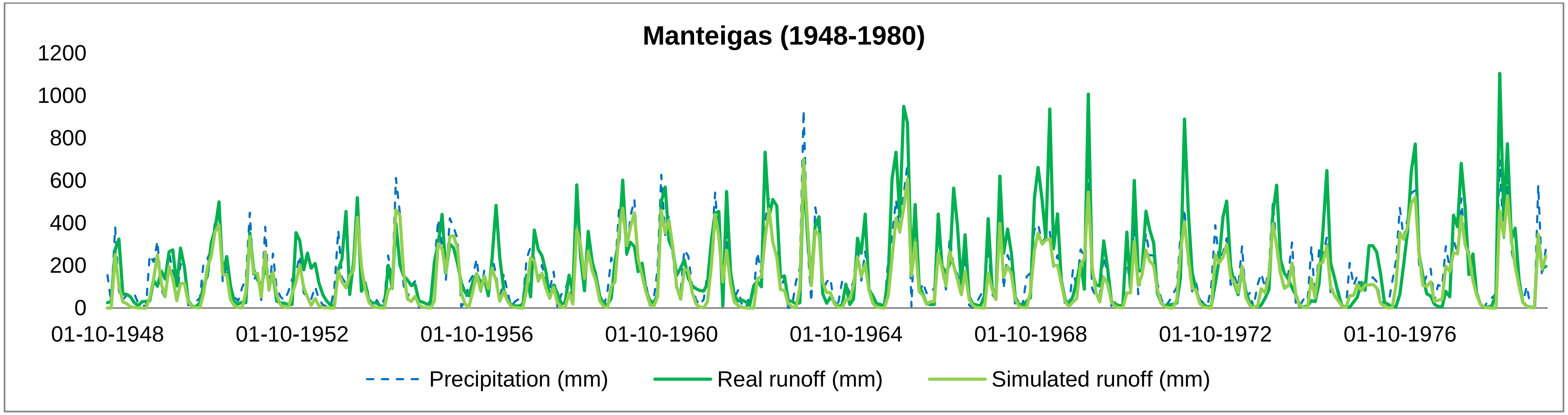


Table 23 - Manteigas, Comparison between precipitation and runoff (real and computed) 1948-1980

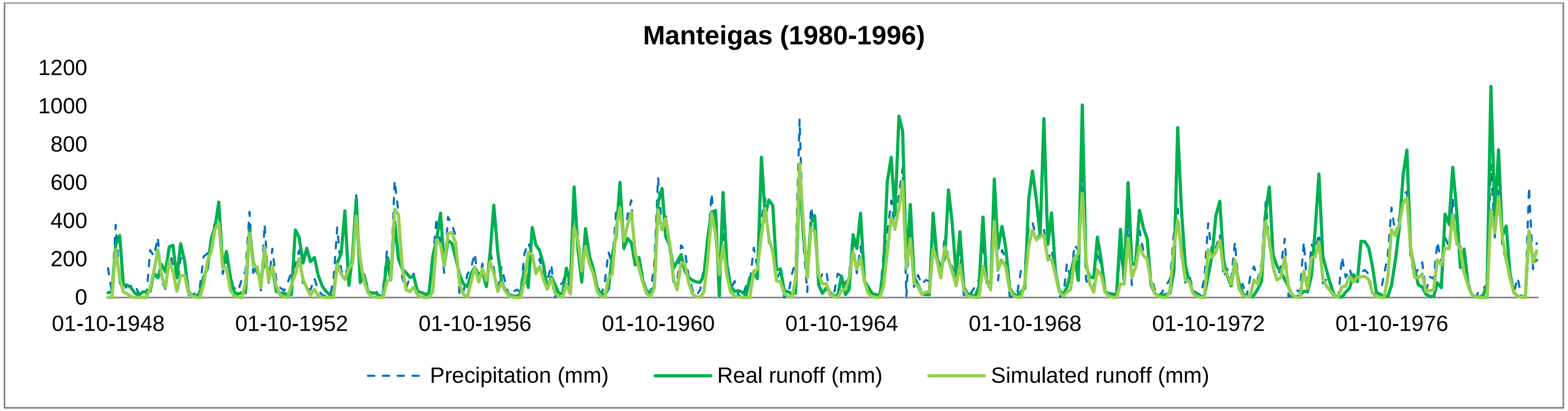


Table 24 - Manteigas, Comparison between precipitation and runoff (real and computed) 1980-1996

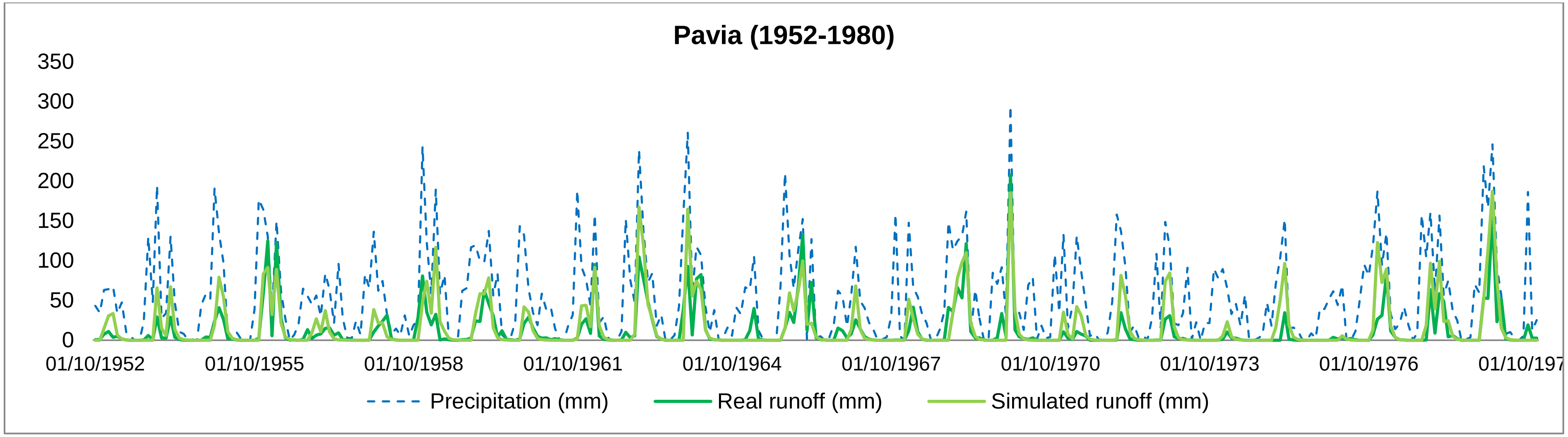


Table 25 - Pavia, Comparison between precipitation and runoff (real and computed) 1952-1980

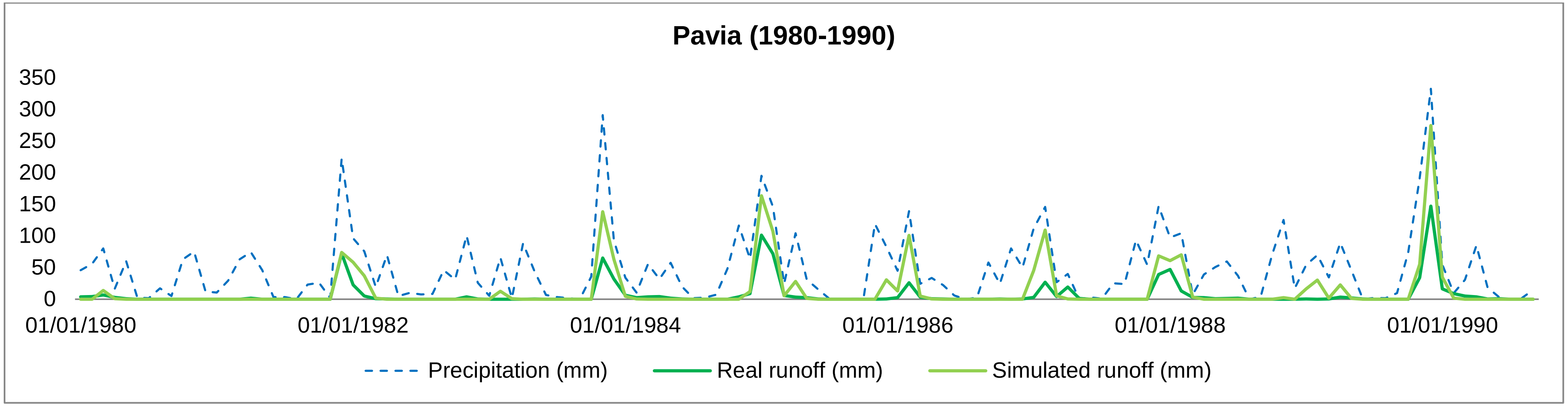


Table 26 - Pavia, Comparison between precipitation and runoff (real and computed) 1980-1990

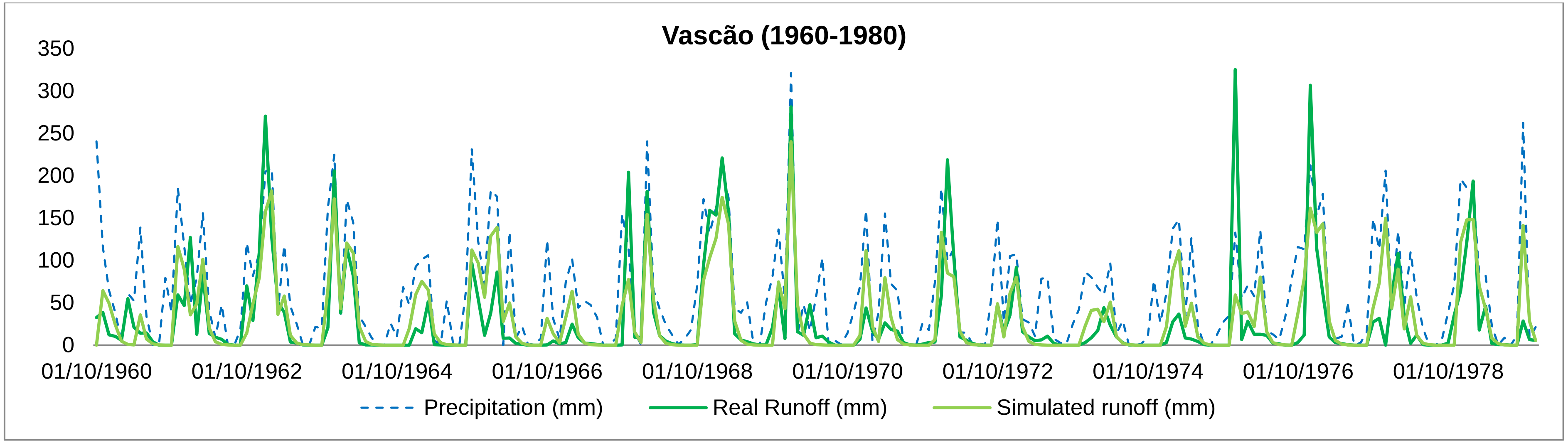


Table 27 - Vascão, Comparison between precipitation and runoff (real and computed) 1960-1980

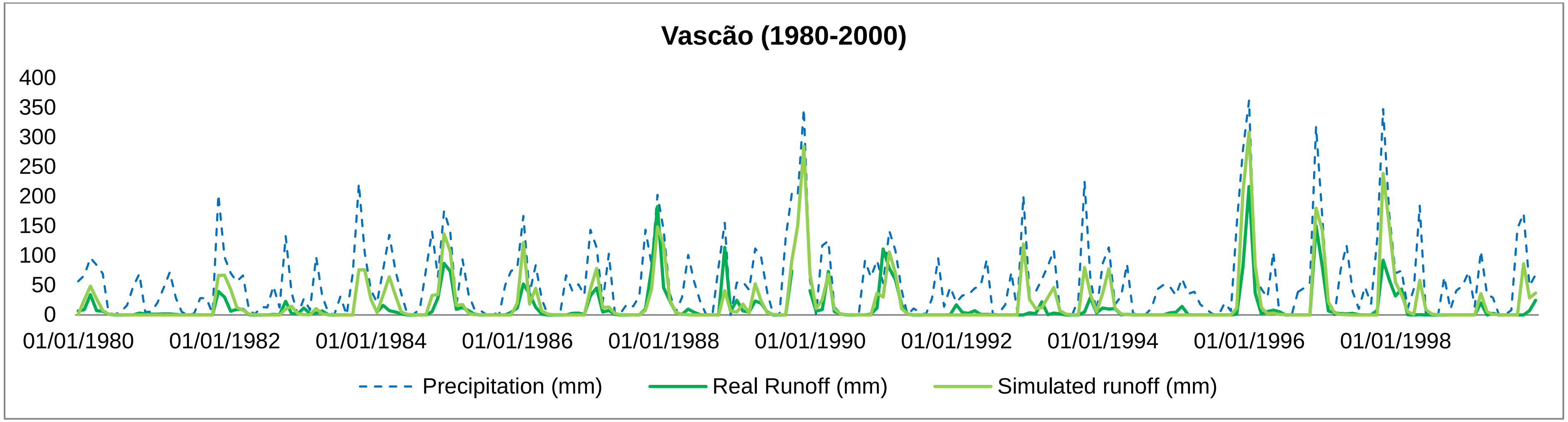


Table 28 - Vascão, Comparison between precipitation and runoff (real and computed) 1980-2000

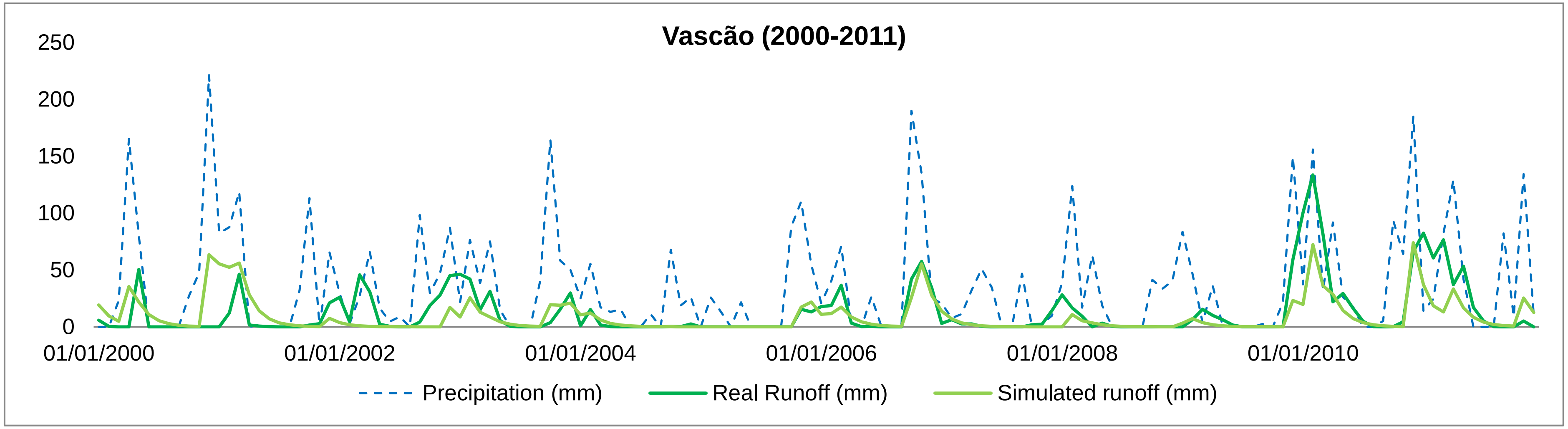


Table 29 - Vascão, Comparison between precipitation and runoff (real and computed) 2000-2011

3.3. Analysis of soil proprieties

Correlations were done to optimize the soil's proprieties values (available water capacity and coefficient of reservoir) was interpreted data from Thornthwaite-Mather model. Green line shows the variation of value of available water capacity (**AWC**) and blue line shows the variation in coefficient of reservoir (***f***).

3.3.1. Gimonde, Bragança

For Gimonde, table 30 shows that the optimized values for all data period was 190 mm for available water capacity and 0,7 for coefficient of reservoir and table 31, 32, and 33 shows the optimization for studied data. Table 34 show the variation of those soil proprieties.

From 1966 - 2004

AWC/f	150	160	170	180	190	200	210	220	230	240	250
0,55	89,6	89,6	89,6	89,5	89,5	89,4	89,4	89,3	89,3	89,2	89,2
0,6	90,3	90,3	90,3	90,2	90,2	90,2	90,1	90,1	90,1	90,0	90,0
0,65	90,6	90,6	90,7	90,6	90,6	90,6	90,6	90,6	90,5	90,5	90,5
0,7	90,7	90,7	90,8	90,8	**90,8**	90,8	90,8	90,8	90,8	90,8	90,7
0,75	90,6	90,6	90,7	90,7	90,7	90,7	90,7	90,7	90,7	90,7	90,7
0,8	90,2	90,3	90,4	90,4	90,5	90,5	90,5	90,5	90,5	90,5	90,3

Table 30 - Correlation values for Gimonde for the whole period (1966-2004)

From 1966 to 1980

AWC/f	260	270	280	290	300	310	320
0,65	91,2	91,2	91,2	91,1	91,1	91,1	91,1
0,7	91,6	91,6	91,6	91,6	91,6	91,6	91,6
0,75	91,8	91,8	91,8	91,8	91,8	91,8	91,8
0,8	91,8	91,8	91,8	**91,9**	91,9	91,9	91,9
0,85	91,6	91,7	91,7	91,7	91,7	91,7	91,7

Table 31 - Correlation values for Gimonde for the interval between 1966 and 1980

From 1980 to 2000

AWC/f	130	140	150	160	170	180	190
0,6	91,1	91,1	91,1	91,1	91,0	91,0	90,9
0,65	91,2	91,3	**91,3**	91,3	91,3	91,2	91,2
0,7	91,1	91,2	91,2	91,2	91,2	91,2	91,2
0,75	90,8	90,8	90,9	90,9	91,0	91,0	91,0
0,8	90,2	90,3	90,4	90,4	90,5	90,5	90,5

Table 32 - Correlation values for Gimonde for the interval between 1980 and 2000

From 2000 to 2004

AWC/f	90	100	110	120	130	140	150	160	170	180
0,6	96,3	96,3	96,2	96,2	96,1	96,0	96,0	95,9	95,8	95,7
0,65	96,5	96,6	96,6	96,5	96,5	96,5	96,4	96,4	96,3	96,3
0,7	96,5	96,6	**96,6**	96,6	96,6	96,6	96,6	96,6	96,6	96,5
0,75	96,3	96,4	96,5	96,5	96,5	96,5	96,5	96,5	96,5	96,5

Table 33 - Correlation values for Gimonde for the interval between 2000 and 2004

	66 to 80	80 to 00	00 to 04
AWC	290	150	110
f	0,8	0,65	0,7

Table 34 - Best values of AWC and *f* obtained from correlations of Gimonde basin

3.3.2. Vale Giestoso, Porto

For Vale Giestoso, table 35 shows that the optimized values for all data period was 210 mm for available water capacity and 0,5 for coefficient of reservoir. Table 36 and 37 shows the optimization for studied data. Table 38 shows the variation of those soil proprieties.

From 1957 to 1990

AWC/f	180	190	200	210	220
0,4	84,5	84,5	84,5	84,5	84,5
0,45	85,2	85,2	85,2	85,2	85,2
0,5	85,4	85,4	85,4	**85,5**	85,5
0,55	85,3	85,3	85,4	85,4	85,4
0,6	85,0	85,0	85,0	85,1	85,1

Table 35 - Correlation values for Vale Giestoso for the whole period (1957-1990)

From 1957 to 1980

AWC/f	170	180	190	200	210
0,45	85,2	85,2	85,2	85,2	85,2
0,5	85,6	85,6	85,6	85,6	85,6
0,55	85,6	85,6	85,6	**85,7**	85,7
0,6	85,4	85,4	85,5	85,5	85,5

Table 36 - Correlation values for Vale Giestoso for the interval between 1957 and 1980

From 1980 to 1990

AWC/f	100	110	120	130	140	150	160	170	180	190	200	210
0,35	85,9	85,9	85,9	85,8	85,8	85,7	85,7	85,7	85,6	85,6	85,6	85,5
0,4	86,4	86,4	86,4	86,4	86,4	86,4	86,3	86,3	86,3	86,3	86,3	86,2
0,45	86,4	86,4	**86,5**	86,5	86,5	86,5	86,5	86,5	86,5	86,5	86,5	85,4
0,5	86	86,1	86,1	86,1	86,2	86,2	86,2	86,2	86,2	86,2	86,2	86,2

Table 37 - Correlation values for Vale Giestoso for the interval between 1980 and 1990

	57 to 80	80 to 90
AWC	200	120
f	0,55	0,45

Table 38 - Best values of AWC and f obtained from correlations of Vale Giestoso basin

3.3.3. Manteigas, Coimbra

For Manteigas, table 39 shows that the optimized values for all data period was 100 mm for available water capacity and 0,75 for coefficient of reservoir and table 40 and 41 shows the optimization for the period of studied data. Table 42 shows the variation of those soil proprieties.

From 1948 to 1996

AWC/f	60	70	80	90	100	110	120	130	140
0,65	84,7	84,7	84,7	84,6	84,6	84,6	84,6	84,6	84,6
0,7	85,0	85,0	85,0	85,0	85,0	85,0	85,0	85,0	85,0
0,75	85,1	85,2	85,2	85,2	**85,2**	85,2	85,2	85,2	85,1
0,8	85,1	85,1	85,1	85,1	85,1	85,1	85,1	85,1	85,1
0,85	84,8	84,9	84,9	84,9	84,9	84,9	84,9	84,9	84,9

Table 39 - Correlation values of Manteigas for the whole period

From 1948 to 1980

AWC/f	50	60	70	140	210	220	230	240	250
0,65	83,5	83,7	83,5	83,4	83,4	83,3	83,3	83,3	83,3
0,7	83,7	83,7	83,7	83,7	83,7	83,7	83,7	83,7	83,6
0,75	83,7	83,8	83,8	83,8	83,8	83,8	**83,8**	83,7	83,7
0,8	83,6	83,6	83,6	83,7	83,7	83,7	83,7	83,7	83,7

Table 40 - Correlation values for Manteigas for the interval between 1948 and 1980

From 1980 to 1996

AWC/f	60	70	170	270	280	290	350	400	410	420
0,7	88,1	88,1	87,9	87,9	87,9	87,8	87,8	87,8	87,8	87,8
0,75	88,4	88,4	88,4	88,3	88,3	88,3	88,4	88,3	88,3	88,3
0,8	88,5	88,6	88,6	88,6	88,6	88,5	88,5	88,5	88,5	88,5
0,85	88,5	88,5	88,6	88,6	88,6	88,6	88,6	88,6	**88,6**	88,5
0,9	88,2	88,2	88,4	88,4	88,4	88,4	88,4	88,4	88,4	88,4

Table 41 - Correlation values for Manteigas for the interval between 1980 and 1996

	48 to 80	80 to 96
AWC	230	410
f	0,75	0,85

Table 42 - Best values of AWC and f obtained from correlations in the Manteigas basin

3.3.4. Pavia, Lisboa

For Pavia, table 43 shows that the optimized values for all data period was 130 mm for available water capacity and 0,85 for coefficient of reservoir and table 44 and 45 shows the optimization for studied data. Table 46 shows the variation of those soil proprieties.

From 1952 to 1980

AWC/f	110	120	130	140	150
0,75	85,1	85,3	85,3	85,2	85
0,8	85,2	85,3	**85,4**	85,3	85,2
0,85	85,1	85,3	85,4	85,3	85,2
0,9	84,9	85,1	85,2	85,2	85,1

Table 43 - Correlation values of Pavia for whole period (1952-1980)

From 1952 to 1980

AWC/f	130	140	150	160	170	180
0,7	84,0	84,0	84,0	84,0	83,9	83,7
0,75	84,1	84,2	84,2	84,2	84,1	84,0
0,8	84,1	84,2	84,2	**84,2**	84,2	84,1
0,85	83,9	84,0	84,1	84,2	84,1	84,1
0,9	83,6	83,8	83,9	83,9	83,9	83,9

Table 44 - Correlation values for Pavia for the interval between 1952 and 1980

From 1980 to 1990

AWC/f	80	90	100	110
0,8	92,7	92,8	92,7	92,4
0,85	93,1	93,3	93,2	93,0
0,9	93,3	93,5	93,5	93,3
0,95	93,2	93,5	**93,5**	93,4
1	93,0	93,3	93,4	93,2

Table 45 - Correlation values for Pavia for the interval between 1980 and 1990

	52 to 80	80 to 90
AWC	160	100
f	0,8	0,95

Table 46 - Best values of AWC and f obtained from correlations in the Pavia basin

3.3.5. Vascão, Beja

For Vascão, table 47 shows that the optimized values for all data period was 80 mm for available water capacity and 0,80 for coefficient of reservoir and table 48 and 49 shows the optimization for studied data. Table 50 shows the variation of those soil proprieties.

From 1960 to 2011

AWC/f	60	70	80	90	100
0,7	73,7	73,7	73,5	73,3	73,0
0,75	74,0	74,0	73,9	73,8	73,5
0,8	74,0	74,1	**74,1**	74,0	73,8
0,85	73,8	74,0	74,1	74,0	73,9
0,9	73,5	73,7	73,8	73,8	73,7

Table 47- Correlation values of Vascão for the whole period (1960-2011)

From 1960 to 1980

AWC/f	10	20	30	40	50	60
0,65	75,2	75,2	75,1	74,9	74,7	74,4
0,7	75,5	75,6	75,5	75,5	75,3	75,0
0,75	75,5	75,8	75,8	75,8	75,3	75,0
0,8	75,6	75,7	75,8	**75,8**	75,8	75,6
0,85	75,2	75,5	75,6	75,7	75,7	75,6
0,9	74,8	75,1	75,3	75,4	75,4	75,4
0,95	74,2	74,6	74,8	74,9	75,0	75,0
1	73,4	73,8	74,1	74,3	74,4	74,5

Table 48 - Correlation values for Vascão for the interval between 1960 and 1980

From 1980 to 2000

AWC/f	70	80	90	100	110
0,75	85,4	85,4	85,3	85,1	84,8
0,8	85,5	85,6	85,6	85,4	85,2
0,85	85,5	85,6	**85,6**	85,6	85,4
0,9	85,2	85,4	85,5	85,5	85,4
0,95	84,8	85	85,2	85,2	85,2

Table 49 - Correlation values for Vascão for the interval between 1980 and 2000

From 2000 to 2006

AWC/f	50	60	70	80	90
0,4	60,5	60,7	60,6	60,2	59,3
0,45	60,7	61,2	61,3	61,0	60,3
0,5	60,4	61,0	**61,3**	61,2	60,7
0,55	59,6	60,4	60,9	61,0	60,6
0,6	58,3	59,5	60,1	60,4	60,2

Table 50 - Correlation values for Vascão for the interval between 2000 and 2006

	60 a 80	80 to 00	00 to 11
AWC	40	90	70
f	0,8	0,85	0,5

Table 51 - Best values of AWC and f for correlations of Vascão basin

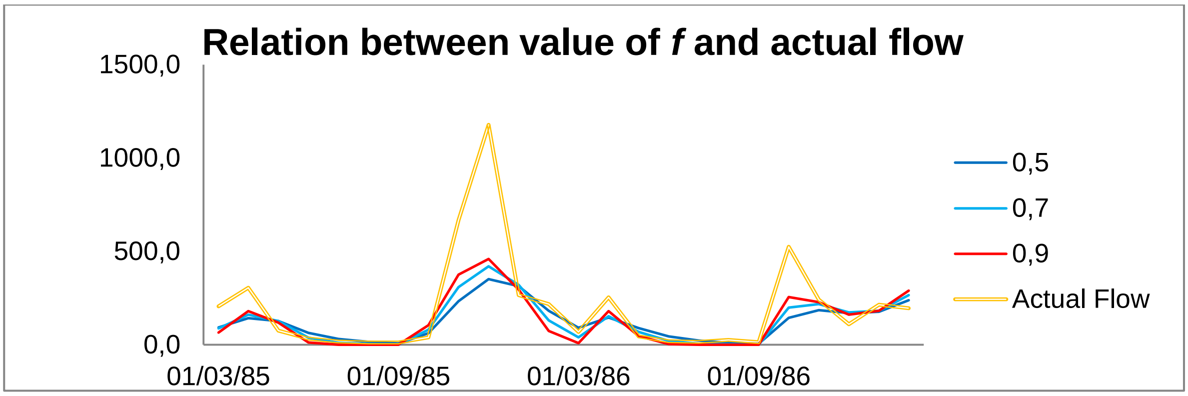


Table 52 - Relation between f value and actual flow

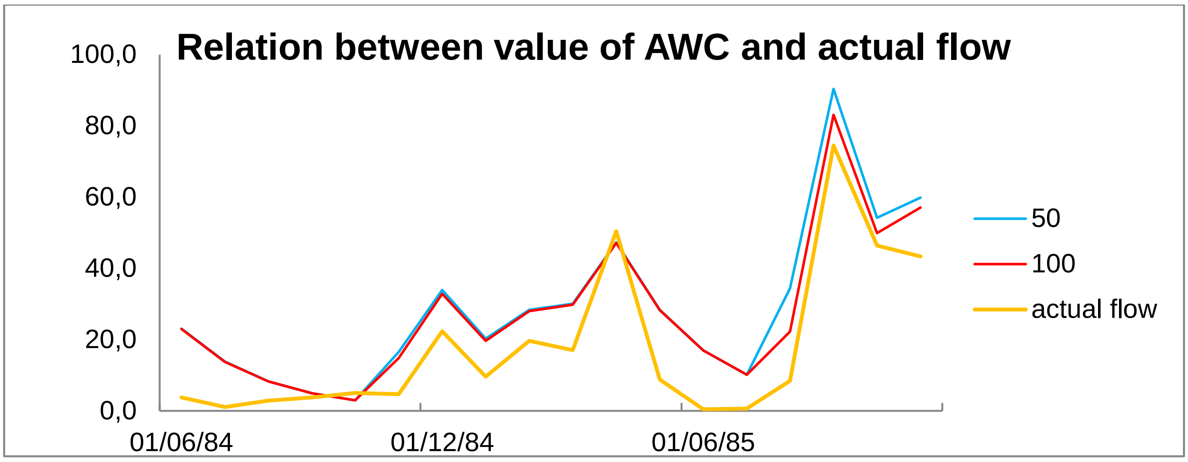


Table 53 - Relation between AWC and actual flow

Observing the graphics 52 and 53 we can conclude that, correlation values can be used to find the closer simulated value of available water capacity (**AWC**) and coefficient of reservoir (***f***) to the value of actual flow obtained from real data from the Portuguese Meteorological Service (Institute of Meteorology).

3.4. Land use

3.4.1. Gimonde, Bragança

Table 54 shows the land use for Gimonde using the new classes. The most significant range was the Broadleaved forests (3) from 1970 to 1990 with a range of -24%.

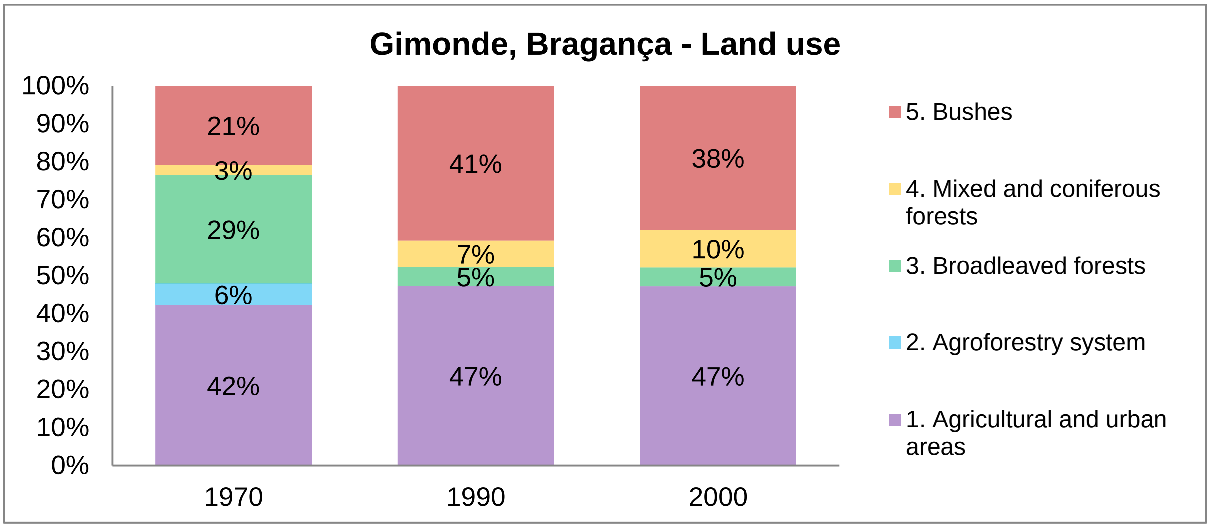


Table 54 - Percentage of land used by each class in the Gimonde basin

3.4.2. Vale Giestoso, Porto

Table 55 shows the land use for Vale Giestoso using the new classes. The most significant range was the Broadleaf forests (3) from 1970 to 1990 with a range of -5%.

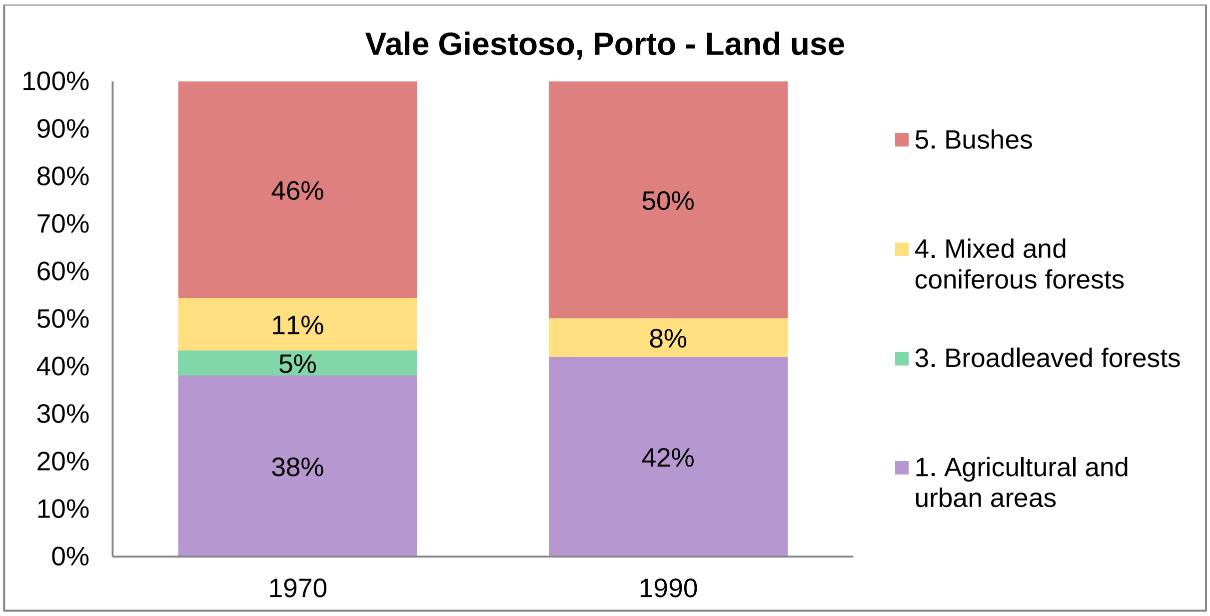


Table 55 - Percentage of land used by each class in the Vale Giestoso basin

3.4.3. Manteigas, Coimbra

Table 56 shows the land use for Manteigas using the new classes. The most significant range was the Mixed and coniferous forests (4) from 1970 to 1990 with a range of 10%.

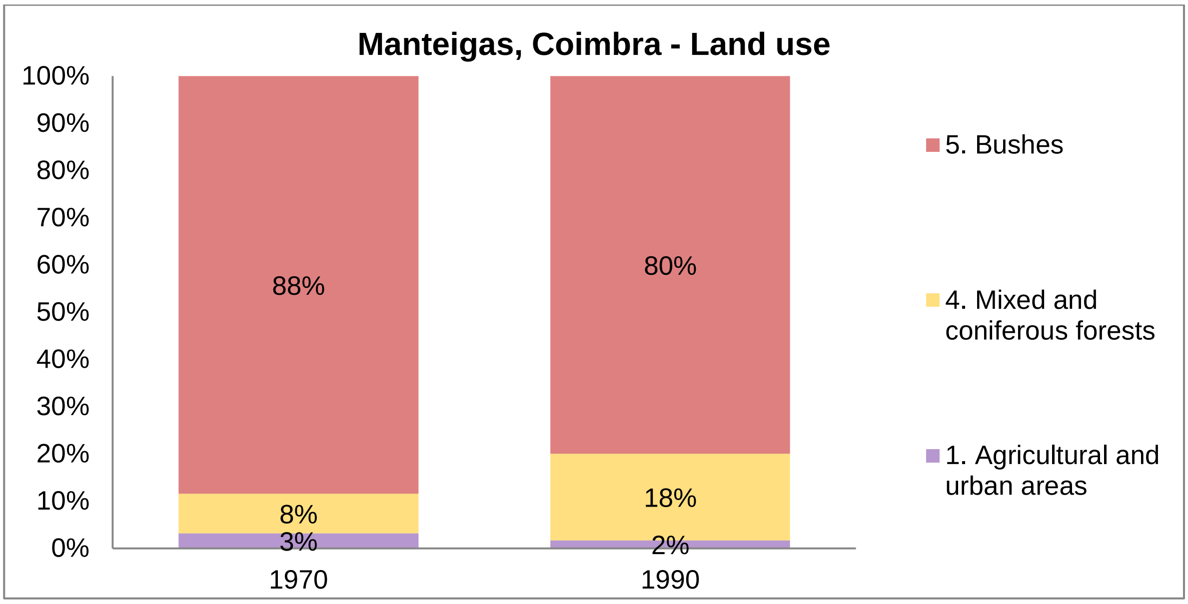


Table 56 - Percentage of land used by each class in the Manteigas basin

3.4.4. Pavia, Lisboa

Table 57 shows the land use for Pavia using the new classes. The most significant range was the Agroforestry system (2) from 1970 to 1990 with a range of 11%.

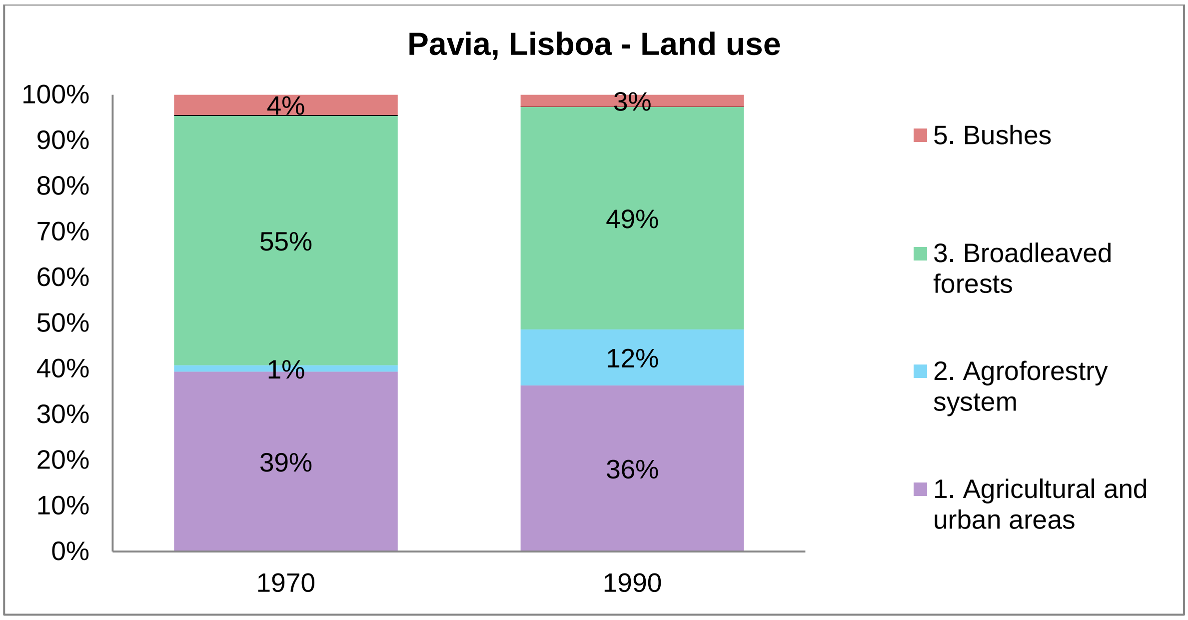


Table 57 - Percentage of land used by each class in the Pavia basin

3.4.5. Vascão, Beja

Table 58 shows the land used for Vascão using the new classes. The most significant range was the Broadleaved forests (3) from 1970 to 1990 with a range of 21%.

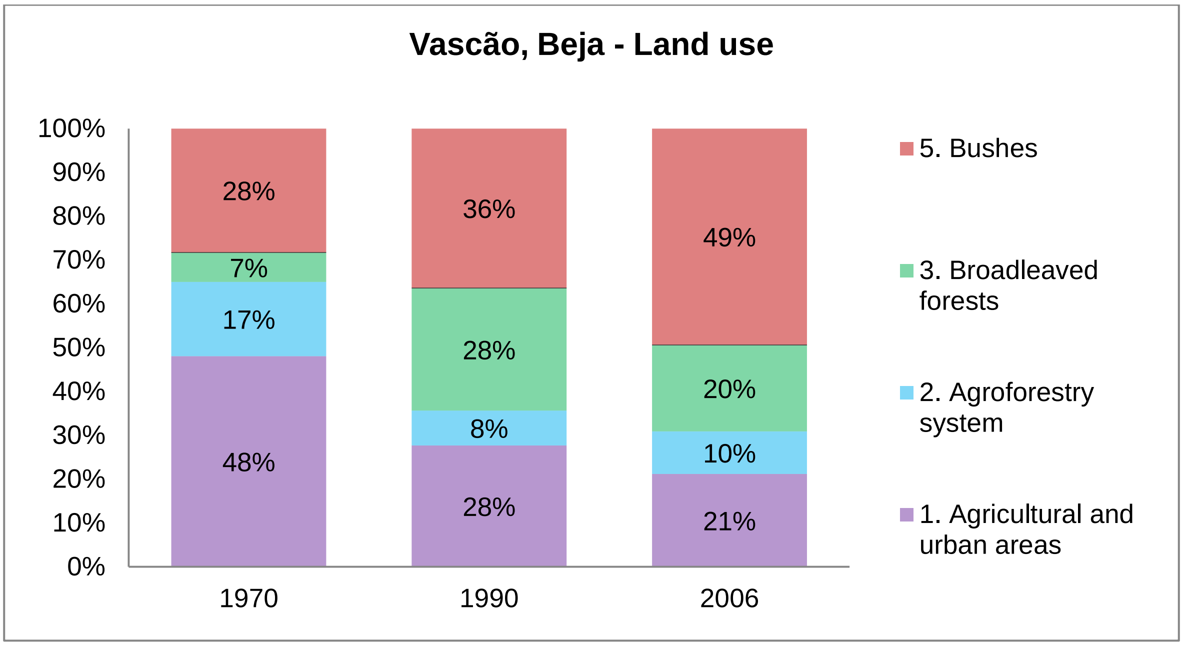


Table 58 - Percentage of land used by each class in the Vascão basin

1. Agriculture and urban areas increase	9%	-22%
1. Agriculture and urban areas decrease	-31%	
2. Agroforestry system increase	13%	-2%
2. Agroforestry system decrease	-15%	
3. Broadleaf forests increase	21%	-22%
3. Broadleaf forests decrease	-43%	
4. Mixed and coniferous forests increase	17%	14%
4. Mixed and coniferous forests decrease	-3%	
5. Bushes increase	45%	33%
5. Bushes decrease	-12%	

Table 59 - Balance of land used ranges in all studied periods

Table 59 shows the range in land use in all studied period. The main class that changes in land use was the in bushes (+33%) and the decrease of Agriculture and urban areas and broadleaf forests (-22%) that contribute to the degradation of landscape.

3.5. Relationship between AWC, f and land used

Table 60 shows a compilation of available water capacity values (AWC), coefficient of reservoir (f) and land used. It presents the results of that relationship. Green values represent the positive variations, red values represent negative variations and yellow values represents the not signification variations.

	G1	G2	VG	M	P	V1	V2		G1	G2	VG	M	P	V1	V2	average
1. Agriculture and urban areas increase	5%		4%					*f*	-0,15		-0,10					**-0,13**
								AWC	-140		-80					**-110**
1. Agriculture and urban areas decrease				-1%	-3%	-20%	-7%	*f*				0,10		0,05	-0,35	**-0,07**
								AWC				180		50	-20	**70**
2. Agroforestry system increase					11%		2%	*f*							-0,35	**-0,35**
								AWC							-20	**-20**
2. Agroforestry system decrease	-6%					-9%		*f*	-0,15					0,05		**-0,05**
								AWC	-140					50		**-45**
3. Broadleaf forests increase						21%		*f*						0,05		**0,05**
								AWC						50		**50**
3. Broadleaf forests decrease	-24%		-5%		-6%		-8%	*f*	-0,15		-0,10				-0,35	**-0,20**
								AWC	-140		-80				-20	**-80**
4. Mixed and coniferous forests increase	4%	3%		10%				*f*	-0,15	0,05		0,10				**0**
								AWC	-140	-40		180				**0**
4. Mixed and coniferous forests decrease			-3%					*f*			-0,10					**-0,10**
								AWC			-80					**-80**
5. Bushes increase	20%		4%			8%	13%	*f*	-0,15		-0,10			0,05	-0,35	**-0,14**
								AWC	-140		-80			50	-20	**-48**
5. Bushes decrease		-3%		-8%	-1%			*f*		0,05		0,10	0,15			**0,10**
								AWC		-40		180	-60			**27**

Table 60 - Relationship between the best AWC and f values optimized and land used

G1	Gimonde period 1	**G2**	Gimonde period 2	**VG**	Vale Giestoso	**M**	Manteigas	**P**	Pavia	**V1**	Vascão period 1	**V2**	Vascão period 2

3.6. Drought analysis

Table 61 shows the new estimation of drought average magnitude value for each drought period.

SPI values	Drought category	Value of DMM
> 0	*No drought*	**0**
0 > SPI > -0,5	*Slight drought*	**1**
-0,5 > SPI > -1	*Moderated drought*	**2**
-1 > SPI > -1,5	*Severe drought*	**3**
-1,5 > SPI > -3	*Extreme drought*	**4**

Table 61 - Drought category and values used to calculate the drought magnitude

Table 62 shows the mains drought periods registered (by magnitude). The biggest drought registered was 01/2004 to 09/2009 and 10/2007 to 02/2010 in Vascão, Beja.

Watershed	Start date	Finish date	DL	Average DMM	DM
Gimonde, Bragança	10/1980	11/1981	14	3,71	51,94
	10/1991	04/1993	19	3,21	60,99
	03/2002	10/2002	8	3,75	30
Vale Giestoso, Porto	02/1965	10/1965	9	3,67	33,03
	11/1975	09/1976	11	4	44
	01/1989	11/1989	11	3,82	42,02
Manteigas, Coimbra	03/1953	02/1954	12	3,83	45,96
	08/1957	05/1958	10	3,1	31
	12/1980	11/1981	12	3,25	39
	01/1992	04/1993	16	3,4	54,4
Pavia, Lisboa	12/1964	09/1965	10	3,6	36
	06/1975	09/1976	16	3,46	55,36
	10/1980	11/1981	14	3,78	52,92
	01/1983	10/1983	10	3,6	36
Vascão, Beja	02/1981	11/1981	10	3,7	37
	02/2002	01/2003	12	3,08	36,96
	01/2004	09/2005	25	3,64	91
	10/2007	02/2010	29	3,62	104,98

Table 62 - Main drought periods found using the SPI value

To confirm the identified droughts, all the computed data was confirmed with Management Plan of Hydrographic Region.

3.7. SCS curve number

The values were compared with number of flows (CN type SCS) with the objective of proving this values. This methodology (CN type SCS) is produced by mapping the geological types of soil on Environment Atlas, produced by the General Directorate of Environment at a scale of 1:1000000. Lobo-Ferreira (1995) uses the hydrologic soil type to calculate the number of flows. According to the methodology used in this study, which was created a new classification of only 5 classes, it was considered that these new classes, following Lobo-Ferreira, do not show significant variations in number of flows.

4. CONCLUSIONS

Were analyzed the response capacities of soil and vegetation that covers the soil. The water taken by precipitation and the drought periods causes changes in land use and in landscape system.

The input data came from a coarse scale, in which it was possible to identify land used but it was not thin enough to identify the specifics cultures in the soil. Thus, it was impossible to apply the knowledge of crop coefficients (K_c) studied by FAO.

In a first view can be concluded that soil response values to water (as available water content and coefficient of reservoir) will vary:

- If the percentage of urban and agricultural area increases (1), the values of available water capacity and coefficient of reservoir decreases, reflecting that the soil has difficulty in reserving water and have less capacity to be transformed into runoff, which proves that, although the soil store fewer water, the agricultural system can consume water that reaches the ground. Urban areas were ignored because there are no area in the watersheds studied.
- If the percentage of agricultural and urban area decreases (1), the values of coefficient of reservoir also decreases, but the values of available water capacity increases, proving the theory described previously. As the agricultural and urban area consumes and exhausts the capacity that the soil has to retain water. A decrease in this area results in a higher capacity of soil to retain water.
- Any changes in the percentage of land used by agroforestry system (2) cause a decrease in the values tested for available water capacity and coefficient of reservoir. This could mean that these changes in land used with agroforestry systems (2) do not directly affect the values studied. The changes are only due, to changes in other types of land used.
- If the percentage of land used by broadleaf forests increase, the available water capacity and coefficient of reservoir values also increases. This could mean that when water falls to the soil, its intercepted by the leaves of plants that compose these soils, downing at a lower speed and thus being in the soil and on the surface, increasing this way the available water capacity and coefficient of reservoir. When the percentage of land used with this culture decreases, happens the opposite.

- Having studied the results of the range of coniferous and mixed forests (4) its not possible to conclude the behavior of soil properties, after an increase of the percentage of used soil by the mixed and coniferous forests (4). Once the range of percentage of land used with this culture decrease just a little, it is not possible to reach any conclusion, because the decrease is not significant (just 3%).
- If the percentage of bushes and vegetation without interest increases, the soil surface is more exposed to erosion and it increases the soil capacity to retain water. The values of available water capacity and coefficient of reservoir decrease. In contrast, the decrease of this percentage of land used causes an increase of other cultures that have more capacity to retain water from the precipitation.

For the land used we can also conclude that the main class that changes in soil used were the bushes (+33%) and the decrease of Agriculture and urban areas and broadleaf forests (-22%) that contribute to the degradation of landscape

During a second step the values of land used and the values of SPI computed, were analyzed, compared and the following conclusions was taken:

- After an exhaustive analyze of all watersheds and all time periods after long droughts, the percentage of soil used by bushes (5) increase, and, expertly on the drought that begins on February of 1981 and finishes on November of 1981 (one of the droughts with less impact), the values of broadleaf forests (3) tends to increase. Considering that the increase of bushes (5), increase also with the erosion and landscape degradation. It is extremely negative considered the impacts of droughts in all ecologic system.

With the objective of trying to prove the theory was studied compared with the methodology of digital map of the number of flows (CN type SCS). This methodology (CN type SCS) is created by mapping the geological types of soil on Environment Atlas, made by the General Directorate of Environment at a scale of 1:1000000. Lobo-Ferreira (1995) uses the hydrologic soil type to calculate the number of flows. According to the methodology used in this study, which created a new classification of only 5 classes, it was considered that these new classes, following Lobo-Ferreira's, do not show significant variations in number of flows.

After using Thornthwaite-Mather Soil Water Balance method an approximation of the values of real and simulated runoff were provided. For calculation, to future analysis the issues about the model such as the use of monthly data and of averages. It is also a problem the fact the model does not take into account the amount of water intercepted by different land uses and the no forecast for different runoff’s. It is important to note that in spite of using a simple hydrological model were achieved satisfactory results.

Thornthwaite-mather water balance model is a single hydrological model that just uses latitude, precipitation and temperature inputs but a most complex hydrological model maybe can find best solutions for this question.

This study can open a new chapter of investigation that can contribute to landscape planning, because it can have a great importance on the planning of the landscape alterations impacts and that’s the landscape architecture’s main goal.

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